Report No. RD-64-88

AD 614622

Final Report

Contract No. FAA/BRD-322

A STUDY OF REQUIREMENTS FOR A PILOT WARNING INSTRUMENT FOR VISUAL AIRBORNE COLLISION AVOIDANCE

December 1963

Project No. 110-504

FEDERAL AVIATION AGENCY
SYSTEMS RESEARCH AND DEVELOPMENT SERVICE
NATIONAL AVIATION FACILITIES EXPERIMENTAL CENTER
ATLANTIC CITY, NEW JERSEY

SPERRY GYROSCOPE COMPANY
DIVISION OF SPERRY RAND CORPORATION
GREAT NECK, NEW YORK

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This report has been prepared by Sperry Gyroscope Company Division of Sperry Rand Corporation for the System Research and Development Service, Federal Aviation Agency, under Contract No. FAA/BRD-322. The contents of this report reflect the views of the contractor, who is responsible for the facts and the accuracy of the data presented herein, and do not necessarily reflect the official views or policy of the FAA.

SPERRY GYROSCOPE COMPANY
DIVISION OF SPERRY RAND CORPORATION
GREAT NECK, NEW YORK

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Sperry Report No. EB-5260-0390

FOREWORD

This report was prepared by the Sperry Cyroscope Company Division of Sperry Rand Corporation, Great Neck, New York for the Federal Aviation Agency, Systems Research and Development Service, National Aviation Facilities Experimental Center, Atlantic City, New Jersey under Contract No. FAA/BRD-322. The research was carried out at the National Aviation Facilities Experimental Center, Atlantic City, New Jersey.

Dr. L. Kaufman, Mr. T. Gold, Mr. D. Blowney, Mr. D. Treffeisen and Mr. J. Workman contributed to the formulation of the program. The principal investigator during Experiments 1, 2 and 3 was Dr. L. Kaufman. The principal investigator during Experiments 4, 5 and 6 was Mr. J. Catalano. Mr. D. Blowney was involved in the experimental design and data reduction of a major portion of the program. Dr. A. Hyman was instrumental in the design of Experiment 6.

The final report was prepared by Mr. J. Catalano and Mr. C. McKown.

Systems Research and Development Service, National Aviation Facilities Experimental Center, Federal Aviation Agency, Atlantic City, New Jersey.

A STUDY OF REQUIREMENTS FOR PILOT WARNING INSTRUMENT FOR VISUAL AIRBORNE COLLISION AVOIDANCE by J. Catalano and C. McKown, Final Report, December 1963, 108 pp., incl. illus.

Project No. 110-504, Report No. RD-64-88

ABSTRACT

The utility of information which would be provided by operational Pilot Warning Instruments (PWI) was studied experimentally in terms of the effect of PWI upon each stage of pilot activity occurring when a pilot is confronted by an intruder, viz., detection of the intruder, evaluation of the intruder threat, and the resulting avoidance maneuver. It was found that PWI improved the probability of detecting intruder aircraft. The extent of improvement was directly related to the amount of the information it provided. In addition, earlier detection, as would occur from PWI information, resulted in earlier evaluation of intruder threat and in earlier maneuvering, when necessary. Effectiveness in the operational situation would, of course, also depend upon such factors as closing rate and angle, range at detection, and aircraft maneuverability.

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SECTION I

INTRODUCTION

This report covers an experimental research program which was conducted for the Federal Aviation Agency. The purpose of this program was the evaluation of the effectiveness of information supplied by Pilot Warning Instruments in reducing the incidence of mid-air collisions. An auxiliary purpose in this research was to determine the kind of information which PWI must provide to the pilot to be effective. The experimental work on the program was accomplished on the F-151 Gunnery Trainer at the National Aviation Facilities Experimental Center (NAFEC) Atlantic City, New Jersey.

The Pilot Warning Instrument (PWI) is one of several types of airborne devices which may prove helpful in preventing collisions. In this report, the term PWI refers to devices which aid visual detection. Such instruments merely warn the pilot of the presence of other aircraft; though they may provide information on the intruder's location, they do not evaluate the nature of the situation nor indicate appropriate maneuvers. Another category consists of Collision Avoidance Systems (CAS), intended to carry out these more complex functions. The PWI, while relatively rudimentary, may be less costly than a CAS. Between PWI and the CAS, there can also be intermediate-level devices falling between the two extremes in terms of the complexity and detail of information they are designed to provide.

In developing this program to evaluate PWI information, the activity undertaken by a pilot when confronted by an intruder was divided into three stages. These were the detection of the intruder, the evaluation of the threat of the intruder, and the maneuver carried out by the pilot to avoid the intruder.

Each of these three stages was to be investigated in detail for, while it might well be that PWI does enable a pilot to detect planes earlier - and at greater ranges - than he normally would, and to detect planes he might not see under normal VFR conditions, it is also possible that this earlier detection is of no value to the pilot in the evaluation of a collision threat because the cues utilized in such an assessment are sub-threshold at far ranges. In this case, because the pilot must wait till he and the intruder are close to properly evaluate the situation, the increased detection range, per se, may not provide useful information.

Again, it is possible that PWI facilitates both detection and evaluation, but does not lead to a greater number of appropriate avoidance maneuvers. If this is so, then such facilitation is irrelevant to the problem of collision avoidance.

There are several ways in which research may be accomplished. One possibility is to review the literature in the area and integrate the findings of studies pertinent to the problem. However, no references were found in the literature which provide answers to the questions under consideration. Therefore, actual experimentation was undertaken.

Such experimentation might have been carried out either in the real world or in a restricted simulated setting. The former would necessitate actual flights in which detection, evaluation and maneuvering under threat conditions would be studied. The problems of generalizing from experimental situations to real situations might be minimized because the physical, biological and psychological conditions would be more similar than in a simulator. Unfortunately, several factors detracted from the advantages of flight testing. Flight tests are very expensive and time consuming. Many flights would be necessary to provide sufficient replication so that results may be considered reliable. Even a more important disadvantage, scientifically, is the lack of control which the experimenter would have over the crucial variables. It would be virtually impossible to vary the stimulus situation with the precision necessary to obtain an adequate experimental design.

Simulated flight offered the advantage of complete control of the experimental situation. Conditions are not subject to atmospheric variation; any specific set of conditions can be obtained at will; simulated flight is much less expensive.

The major disadvantage of simulated experimentation is that it differs from the real world, which is where the findings must ultimately be applied. Many of the visual cues which the pilot uses in flight are not present in the simulator. For example, in the simulator the state of accommodation of the pilot's eye is set for a constant distance of 10 feet. This is the distance at which a target appears when projected on the dome. When looking out at the real empty sky, accommodation under certain conditions will be set for about six feet (high altitude myopia) and shift essentially to infinity when the eyes are stimulated by clouds and other distant objects. If empty field myopia is experienced, then distant targets will be blurred when imaged on the retina and detection performance will be degraded. This effect cannot be simulated.

Another important difference is that the simulator dome brightness is about 3 foot lamberts, whereas the brightness of the real sky may range from near zero to 4000 foot lamberts. These numbers become more meaningful when one realizes that the brightness of a page of white paper in a well illuminated room is about 30 foot lamberts and the mean day brightness of the sky is about

3000 foot lamberts. It is known that detectability of an intruder of constant contrast ratio will vary markedly with background brightness. It is obvious that we cannot sample all of these background brightnesses in the simulator.

A further related difference is that the sky brightness is not homogeneous. Looking at a portion of the sky in the vicinity of the sun will cause the eye to become relatively insensitive to targets in other less bright portions of the sky. The same holds true of the effects of flying over a bright snow-covered terrain. This shifting of adaptation level of the eye cannot easily be produced in the simulator.

Other differences between the simulator and the real world which may affect aspects of the program other than detection are

- The pilot feels no "g's", therefore maneuvers may not be equivalent.
- The lack of detail in the projected image eliminated cues which may be useful in threat evaluation.
- The simulator, which has flight characteristics of an F-100A, is more difficult to fly than a commercial aircraft. Therefore, the results obtained may not be typical of pilot performance in other types of planes.

Several psychological differences also exist in the pilot's reactions to the simulator as opposed to the real world. It would not be expected that the same anxiety would be experienced by the pilot when he encounters a simulated collision as a real collision. In the simulator, a pilot may wait much longer to initiate an avoidance maneuver, since there is no real danger.

The approach of the present program makes it possible to circumvent some of the differences. It is assumed, (for reasons detailed in Section II) that to a first approximation, targets of small angular subtense having equal probabilities of detection when fixated will also have equal probabilities of detection when an observer must search for them; prediction of detection probabilities in the real world is then possible when the physical conditions are specified. Probability of detection under search is a function of the following factors:

- Search time
- Target information
- Work load
- Intrinsic probability (probability of detection when fixated).

The relationships between these factors can be determined in the simulator. Extrapolation to the real world will be possible if real-world intrinsic probabilities are known. A program might be carried out to determine real intrinsic probabilities for a variety of conditions. However, even if these values are not known, it is still possible to obtain measures of the relative effectiveness of different levels of PWI in the simulator.

The results obtained in the simulator concerning threat evaluation and maneuver are not readily generalized to real-world conditions, because even less is known about the cues which the pilot uses in accomplishing these functions than about the process of detection. However, simulator research may be the only practical way to obtain any insight into the pilot's performance in these areas because of the difficulty in achieving true collision situations in actual flight and the difficulty of determining the actual degree of collision threat, not to mention the hazards to the participants in such a flight test program.

Although the relationship between real-world results and simulator results in these last two categories are somewhat nebulous, some constraints on the range of real-world results can be inferred from the simulator results. For instance, in collision cases, it is expected that the pilot's performance in threat evaluation and maneuvering would be at least as good as that obtained in the simulator.

The advantages of simulator research far outweigh the disadvantages. The primary considerations which make simulation desirable are that it is relatively inexpensive and it allows for experimental control. It also allows for the modification and reformulation of concepts so that, if extended to real situations, they are more than untested hypotheses.

SECTION II

EXPERIMENTAL PROGRAM

A. PLAN

A review of the program plan will be presented in this section and the rationale underlying the experiments will be summarized.

The sequence in this report follows the chronological order in which the experiments were carried out. There were several practical reasons for doing the experiments in the order in which they were done. For example, Experiment 3 follows directly from Experiment 1 but Experiment 2 answers a related question which affects, in part, the design of Experiment 3.

As previously mentioned, the program may be regarded as consisting of three phases, each concerned with answering a specific question.

Phase I - The Effect of PWI on Detection (Experiments 1, 1A, 2, 3 and 6)

Fundamentally, all visual collision avoidance techniques are limited by the sensitivity of the human eye. If the pilot is unable to see an intruder, he cannot assess the nature of the threat nor can he perform an avoidance maneuver. If he can see the intruder, then the range at which he first sees it will, in part, determine the time available for him to act upon the visual information.

The visual detection process can be best understood by analyzing threshold curves which are obtained under various conditions. A threshold curve is essentially a function relating probability of detection to the physical characteristics of a target. As shown in figure 2-1 the curve is normally S shaped. The curve at the left represents a larger target than that of the curve at the right. The larger target can be seen more easily, at a given contrast, than the smaller target represented by the curve at the right. (Contrast is defined as the difference between the background and the target brightness, divided by the background brightness). As may be seen, for a particular probability of detection two targets differing in size have different contrasts.

The probability of detection under search conditions can be expected to be lower than with the same target fixated. If an observer must search a wide field for only a limited period of time to find a target, he is not as likely to detect the target as when he fixates it. Probability of detection may also be reduced by distracting tasks, size and complexity of the visual field, and boredom.

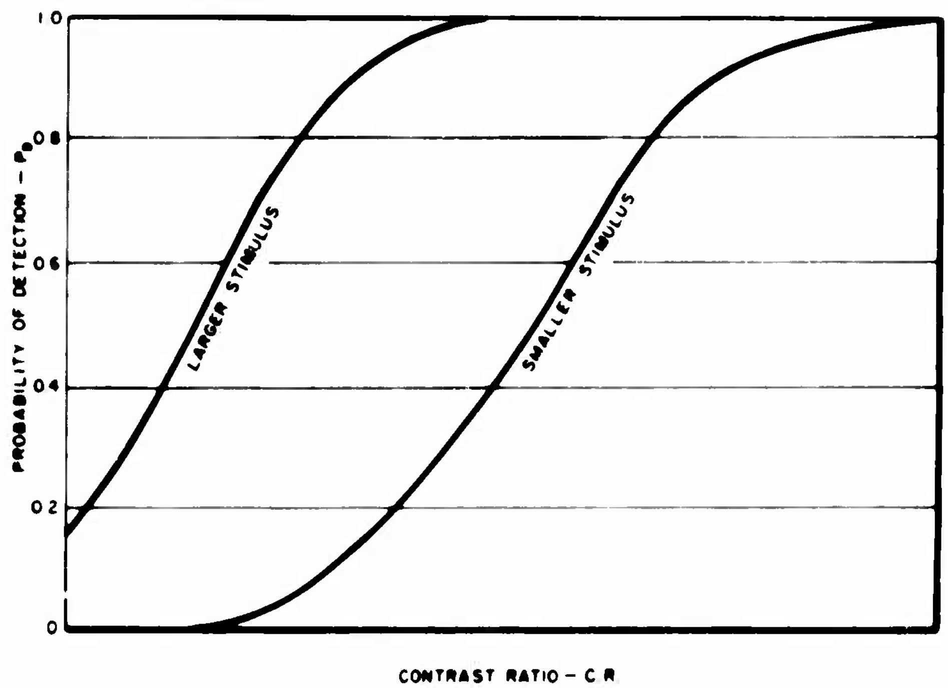

FIGURE 2-1. PROBABILITY OF DETECTION VS CONTRAST RATIO

The function of PWI with regard to detection is to alert the pilot and perhaps constrain his field of search. As the field of search becomes more and more constrained, it approaches the point at which the eye of the pilot is fixated on the target. This is the theoretical limit of a visual collision avoidance system.

As previously mentioned, one of the goals of this study is to find out how various levels of PWI affect the frequency with which intruders are detected. The levels of PWI may range from a simple warning — with no location information, to the provision of precise azimuth and elevation information. The present study is concerned only with the functional characteristics of PWI and not with any particular PWI display nor the development of hardware. Any information given to a pilot is verbal. The level of PWI can be evaluated by determining how it constrains his field of search and affects the probability of search detection.

One approach which may be taken in the evaluation of PWI is based on an assumption. This assumption is that targets having equal probabilities of detection when fixated will have equal probabilities of detection under search. If two targets differ in their physical dimensions, but have equal probabilities of detection when fixated, it is assumed that they will also have equal probabilities of detection when the observer must search for them. The term intrinsic probability of detection (P_I) will be used to refer to the probability of detection when the region of appearance of the target is fixated. The probability of detection associated with a target when the observer must search for the target will be referred to as P_S. This term will apply when the pilot must find the target with or without the help of PWI, within a given period of time. Once the relation between P_I and P_S is known, then to determine the likelihood of a pilot's detecting a target when flying, the P_I for a given set of atmospheric and other environmental conditions may be used. An empirical test of the equivalence assumption is described in Section VI (Experiment 6).

In Experiments 1 and 1A intrinsic threshold curves were established. These curves show the probability of target detection when fixated, as a function of target size and brightness.

Experiment 2 was designed to determine the relationship between the precision with which angular information is presented to the pilot and the detection of targets.

The purpose of Experiment 3 was to determine, for various levels of PWI, the search threshold curves, i.e., the probability of detection in search as a function of intrinsic probability.

It was expected that search threshold levels would vary as a function of the presence or absence of PWI and also as a function of the variance in the pilot's search behavior, depending on whether he was flying his aircraft or acting as a passive observer. The importance of this experiment is that it demonstrated the effectiveness of different PWI levels. The magnitude of the differences was also determined.

Phase II - The effect of PWI on the Evaluation of Collision Threat (Experiment 4)

If PWI can increase the range at which an intruder is detected, it will allow more time for the pilot to look at a particular intruder and evaluate the extent of collision threat. The evaluation of the intruder may depend upon the observed angular velocity (sight-line rate) and the observed rate of change in angular subtense (range rate) of the intruder. If the sight-line rate of the intruder is well above the motion perception threshold of the pilot, then he can be fairly certain that the intruder is on a non-collision course. If the sight-line rate is below threshold, then the observer cannot be completely certain of the degree of threat. However, if the sight-line rate is subthreshold and there is a perceptible range rate of a certain magnitude, then it may be assumed that the threat will be evaluated as a collision by the pilot. Motion thresholds are not single valued. Sight-line rate thresholds depend upon whether or not the field is structured. Range-rate threshold depends upon the luminance of the target as well as range. Therefore control for the factors of field structure, target brightness (meteorological range) and range were provided.

If PWI has an effect on evaluation, then it may be presumed that the pilot can extract information regarding the nature of the threat shortly after detection. Thus the degree of threat, as represented by different levels of miss distance, were varied together with the range at which the pilot made his initial detection. The pilot was to indicate whether or not he thought each intruder was on a collision course.

Phase III - Maneuver time

Experiment 5 was designed to determine the effect of PWI on the time at which a pilot maneuvers, and the appropriateness and effectiveness of his maneuver. Since the usefulness of PWI depends upon its enabling pilots to avoid collisions that otherwise would have occurred, maneuvering performance was studied. If PWI has no effect on this performance any benefit it may have produced in the detection or evaluation of intruder aircraft would be irrelevant to the problem of Collision Avoidance.

The basic question studied in Experiment 5 was "Can the pilot effectively make use of the increase in detection range resulting from PWI?" Ideally, PWI would allow a pilot to maneuver while at a greater range from intruding aircraft than he otherwise would.

The three phases described allow for a complete evaluation of PWI.

The effectiveness of such an instrument can be related to each of these phases so that individual analysis of interactions between PWI and the different activities of the pilot when confronted with the threat of collision will be possible.

The program also indicates requirements which any potential designers of Commercial PWI should consider. These are the level of information which such an instrument should provide and the resolution of bearing information that is sufficient for the pilot's use.

B. SIMULATION FACILITY

The experimental program was carried out using the government-furnished F-151 fixed aerial gunnery trainer and an F-100A flight simulator. A schematic diagram of the simulator is shown in figure 2-2. The target source is located in the model housing at the right end of the range bed and the light reflected from it is focused by an optical system and relayed via the mirrors to project a real image on the dome. The target can vary in size with range and change aspect angle and position in azimuth and elevation in correspondence to the relative movements of the F-100A and its own programmed dynamics. A horizon projector forms a shadow horizon on the dome which also moves in correspondence with the F-100A maneuvers. Target brightness is controlled in discrete steps by use of neutral density filters placed in the filter wheel. Brightness may also be continuously varied by an optical stop located in the target projection system.

Certain modifications of the simulator were made for this program. An experimental requirement was that the luminance of the dome be homogeneous to within five percent at an absolute luminance level of not less than three foot lamberts. This was accomplished by the use of a "circle line" fluorescent lamp (for ambient illumination), combined with a frosted incandescent lamp which was located inside an opaque hemisphere (to produce the horizon). The inner portion of the fluorescent lamp was painted black. The original projection lens and mirrors were replaced with items of higher quality in order to obtain images of desired clarity and color. The target image was a bright silhouette of a fighter type plane. The target was relatively homogeneous in brightness and lacked detail. When pilots were asked to judge the type of plane the image represented their most common responses were that it was an F-84.

In cases where no field structure was desired, the background illumination was made as homogeneous as possible, except that the horizon line, mentioned above, was still projected. When field structure was desired, the images of clouds were also projected on the background.

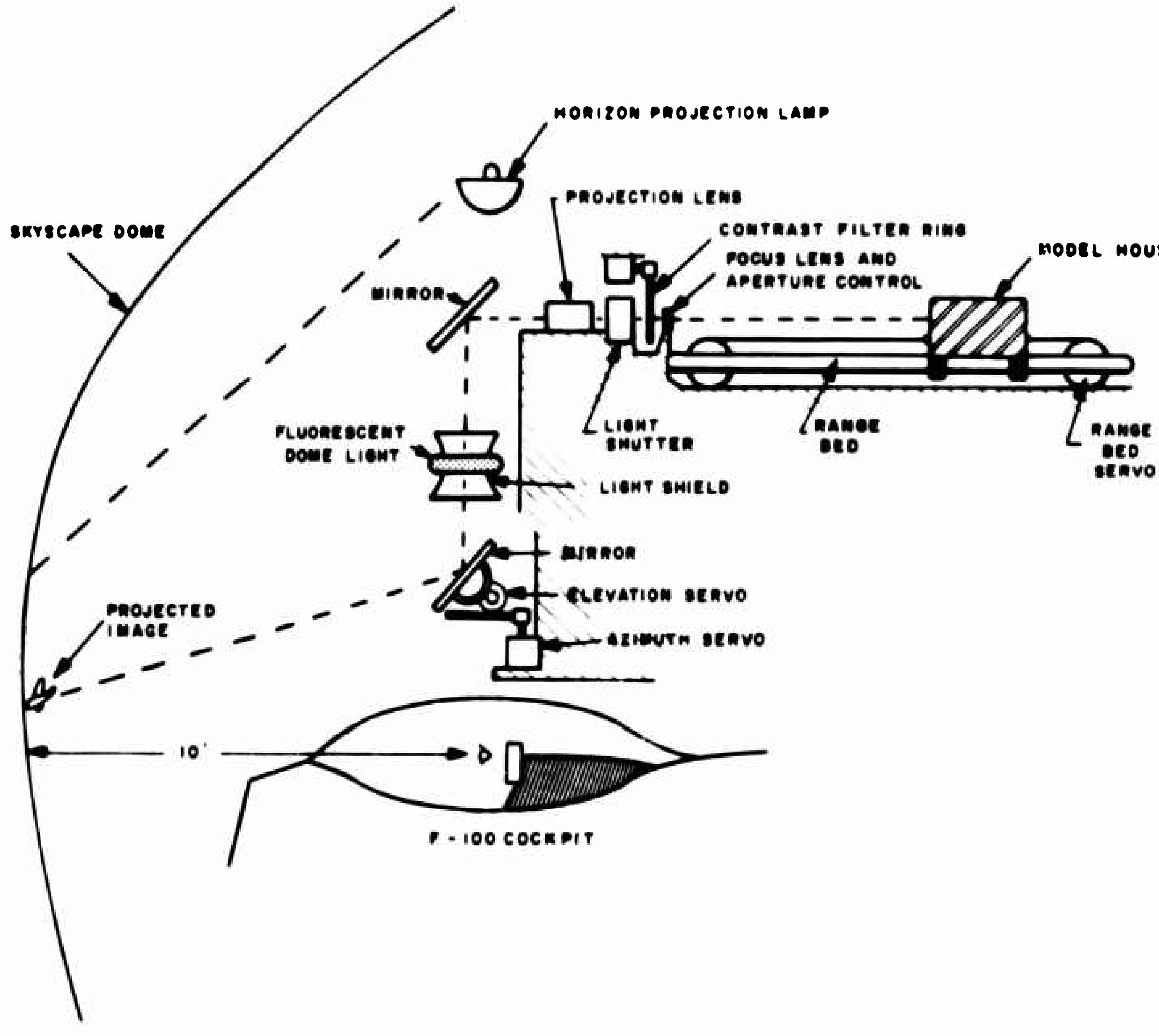

FIGURE 2.2. SCHEMATIC REPRESENTATION OF FLIGHT SIMULATOR

SECTION III

DETAILS OF THE EXPERIMENTS

EXPERIMENT 1

A. PURPOSE

It was the purpose of Experiment 1 to determine the intrinsic threshold curves in the simulator as a function of target size and contrast ratio. Intrinsic threshold is defined as the probability of target detection by an observer when fixating the region of the appearance of the target. Thus, in this experiment no search was required.

Due to apparatus inadequacy, constant target characteristics could not be maintained during the course of Experiment 1. It is being reported, nevertheless, because of its possible interest to a specialized audience. The reader may proceed directly to Experiment 1A which has replaced Experiment 1 in the treatment of the total study.

B. METHOD

In accordance with the purpose of the experiment, target size and target contrast ratio were employed as independent variables. Frequency of target detection was taken as the dependent variable. Four levels of size and six levels of contrast nested within size were employed. Target size was defined as the angular subtense of the diameter of an imaginary circle circumscribing the target (wingspan from head-on view). The levels of size were chosen a priori to be 3, 5, 7, and 20 minutes of arc at the eye of the subject. Five of the levels of contrast ratio were set in a series of pilot runs. The sixth level of contrast ratio was chosen a priori to be zero, so that no target was presented. These sham trials were used to correct the data for guessing. Target presentation time was chosen a priori to be ten seconds.

Each level of size and contrast ratio was presented to each of eight non-pilot subjects 52 times. This procedure yielded a total of 9984 trials. Targets were presented to the subjects in sessions of 78 trials each. Target size was constant during a given session while the order of presentation of the levels of contrast ratio was randomized within each session. Further, the order of the sessions for each subject was randomized.

Target size was controlled by positioning the model housing on the range bed by means of the range servo. Target contrast ratio was controlled by placing different neutral density filters in the light path of the projection system. These were mounted on a filter wheel. Since different ranges of contrast ratio were required at each size, it was necessary to set the target brightness at a fixed filter wheel position prior to each session. In addition the background brightness was checked, and, if necessary, set to 3.1 foot lamberts before each session. This level of background brightness was chosen so that the brightness of the background would not drop below 3.0 foot lamberts at any point on the visual field. These measurements were accomplished with a Spectra-Spot Brightness Meter Model 1505-UB. This instrument was calibrated prior to each session.

Two fixation points were affixed to the dome directly in front of the subject. Targets appeared between these points. The subjects were told that when they heard a tone in their headset, a target might appear between the two points. They were to indicate by means of two switches mounted on a box held in their lap whether or not they detected a target. The experimenter recorded their response.

A series of pilot runs was conducted to establish and test this detailed procedure. As a result, two changes were made in the procedure. These were:

- Removal of the fixation points from the dome
- Reduction of the presentation time from ten seconds to one second.

These changes in experimental procedure are discussed in the following paragraphs.

1. Fixation Point Removal

The use of fixation points for controlling the subject's eye position presented certain difficulties. While the points insured foveal target detection, targets of less than 100-percent intrinsic threshold could not be found by the subjects when they searched the dome. Consequently, intrinsic threshold values measured in this way could not be used as predictors of search probabilities of detection with various level of PWI, i. e. , search time was very large . A number of reasons can be cited for this condition. The first of these is the fact that the fixation points permitted the eye of the subject to be accommodated for the distance at which the target appeared. When the subject searched the dome, however, his eye may not have been accommodated for the 10-foot distance because of an empty field effect. This difference in accommodation can raise the contrast thresholds for target detection when searching (Whiteside, 1957). A second consideration is that the black fixation spots may have produced a target contrast-enhancement effect (Wallach, 1948). A third factor is that the fovea occupies an extremely small portion of the sensitive retina. Consequently, there is a small probability that the fovea will dwell long enough on all possible points on the dome at which the target may appear. Since the targets viewed with fixation points present are detected foveally, if they are of small angular subtense they may not be detected as readily by the parafovea with the photo-pic eye. Consequently, they are not seen in search because of the very brief dwell time.

To compensate for these factors, the fixation points were removed and the subject was instructed to look straight ahead. This did three things: first, the accommodation of the eye was the same in search as in the intrinsic-threshold measurement trials; second, any objectionable contrast-enhancement effects were eliminated; and, third, the eye tended to wander a bit, making the target a mixed foveal and parafoveal image. This is a more realistic way to calibrate subjects for a base line from which search detection probabilities can be predicted. Some data were also taken with the fixation points present to determine the actual performance differences.

2. Presentation Time

It was found during the pilot runs that a one-second exposure time for the target image presentation yielded results identical to those using a ten-second exposure time. In the interest of experimental economy, a one-second target exposure was employed in the experiment.

C. RESULTS AND TREATMENT OF DATA

This section contains a summary of the raw experimental results and the results of the various steps in the data reduction procedure which are pertinent to the interpretation of the experiment.

The raw data of the experiment are summarized in tables 1 and 2. These results are in the form of the proportion of 52 target presentations on which subjects reported seeing targets.

It will be noted that table 2 presents the raw data for subjects 3 and 4 while table 1 shows the data for subjects 1, 2, 5, 6, 7, 8, 10 and 11. The results for subjects 3 and 4 are shown separately because their data was not included in the final analysis. They were discarded because at contrast ratio of 0, (sham trials), their guessing probability was greater than 50 percent on the average. This atypical high guessing probability suggests that these subjects were using criteria which differed significantly from the remaining subjects. Subject 9 was not included in the sample because his performance was obviously so erratic in the course of the test that his runs were not completed. Only the data of the eight subjects shown in table 1 entered into the final plotting of the intrinsic probability of detection curves of figures 3-1, 3-2, 3-3 and 3-4.

The guessing probabilities, (responses to the sham trial), were first checked for homogeneity over sizes but within subjects. In all cases these probabilities proved to be homogeneous at the five-percent level of significance. They were therefore pooled within subjects and the detection probabilities corrected for guessing were obtained. The correction for guessing was made in the classical manner by applying the formula (Finney, 1947)

$$P_D = \frac{(P_S - P_G)}{1 - P_G}$$

where

P_D = detection probability

P_G = guess probability

P_S = seeing probability

The detection probabilities were then subjected to a Friedman two-way analysis of variance (Siegel, 1956) to determine if the subjects were responding in the same manner to the same stimuli.* The values of the test statistic χ^2_r, together with the critical value of the statistic for the five-percent and one-percent levels of significance are tabulated below:

Size (Minutes of arc)	χ^2_r	Critical 5%	Value 1%
20	21.7	14.1	18.5
7	26.3	14.1	18.5
5	23.0	14.1	18.5
3	23.3	14.1	18.5

Thus, since χ^2_r exceeds the critical value, one must reject the hypothesis that all subjects respond in the same way to the same stimuli on the basis of this test. However, it must be remembered that this test is sensitive to rank of score only and not to magnitude. Inspection of the data made it apparent that the magnitude of difference among the subjects was not sufficiently great to make an important operational difference.

The following procedure was employed to check this conclusion. It was found that when the experimental data was censored by removing subjects 2 and 11, the remaining subjects responded to the same stimuli in the same way. The results of the Friedman two-way analysis of variance for the censored sample are tabulated below:

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*In this test the 8 subjects were considered to be columns and the contrast ratios were considered to be rows.

Size (Minutes of arc)	χ^2_r	Critical 5%	Value 1%
20	12.2	11.1	15.1
7	14.5	11.1	15.1
5	5.3	11.1	15.1
3	11.1	11.1	15.1

Therefore a probit analysis (Finney, 1947) was performed on the detection probabilities pooled over subjects for both the censored sample and the uncensored sample. The results of these two analyses are tabulated below:

	Size (minutes of arc)			
	20	7	5	3
Mean Contrast Ratio				
Uncensored	5.41×15^{-2}	2.41×10^{-1}	4.50×10^{-1}	1.71×10^{0}
Censored	5.50×10^{-2}	2.62×10^{-1}	4.85×10^{-1}	1.83×10^{0}
Standard Deviation				
Uncensored	1.73×10^{-2}	8.55×10^{-2}	1.38×10^{-1}	6.49×10^{-1}
Censored	1.72×10^{-2}	7.70×10^{-2}	1.29×10^{-1}	6.37×10^{-1}
σ/M				
Uncensored	0.32	0.35	0.31	0.38
Average: 0.34				
Censored	0.31	0.29	0.27	0.35
Average: 0.31				

The curves arising from these values are plotted in figures 3-1, 3-2, 3-3, and 3-4. As may be seen, the results do not differ greatly.

Unfortunately, the obtained data were not useful for application in the search studies because target characteristics changed over time due to the intense heat produced by the illumination system. It was impossible to obtain replacement models which would yield identical luminance distributions so that other models could not be used as replacements. In the interest of obtaining stimuli which would remain constant, it was decided that sturdier and more easily duplicable circular targets would be used. Since circular targets have been commonly used in threshold studies, this shape was chosen in preference to other simple shapes.

Use of the new targets required the determination of their intrinsic probabilities associated with various contrast ratios. Experiment 1A was carried out to do this.

TABLE 3-1

SUMMARY OF EXPERIMENTAL DATA

Size (minutes of arc)	Contrast Ratio	Subject 1	2	5	6	7	8	10	11
20	0.0968	0.9615	1.0000	1.0000	0.9038	1.0000	0.9423	1.0000	0.9423
	0.0774	0.8077	0.9615	0.9423	0.8462	0.9423	0.9423	0.9231	0.8846
	0.0619	0.6346	0.9615	0.9423	0.7885	0.8269	0.6923	0.8269	0.7692
	0.0484	0.2308	0.6154	0.6538	0.5192	0.5000	0.3462	0.3462	0.3462
	0.0387	0.0962	0.2692	0.2500	0.1538	0.0962	0.1538	0.1346	0.1154
	0.0000	0.0000	0.0000	0.0769	0.0577	0.0192	0.0769	0.0962	0.0577
7	0.3920	0.9615	1.0000	0.8077	0.9615	0.9808	0.9231	0.8654	0.9615
	0.3136	0.8846	1.0000	0.5769	0.8846	0.9231	0.7308	0.6346	0.9423
	0.2508	0.6923	0.9808	0.5577	0.7500	0.7500	0.5385	0.5769	0.8077
	0.1960	0.3462	0.7885	0.1538	0.3077	0.1538	0.2308	0.1731	0.4231
	0.1568	0.0577	0.3654	0.0962	0.2500	0.0769	0.1346	0.1346	0.1731
	0.0000	0.0000	0.0769	0.1154	0.0577	0.1154	0.0962	0.0385	0.0192
5	0.6581	0.9038	1.0000	0.8462	0.8654	0.9615	0.8462	0.8654	0.9808
	0.5264	0.6923	0.9808	0.6731	0.6923	0.7885	0.5962	0.5385	0.9615
	0.4212	0.4423	0.8846	0.5000	0.5577	0.5769	0.2692	0.3654	0.8846
	0.3290	0.0385	0.5385	0.1538	0.2692	0.0962	0.1538	0.0962	0.4038
	0.2632	0.0577	0.2692	0.0769	0.1154	0.0577	0.1538	0.0577	0.1346
	0.0000	0.0513	0.0385	0.1731	0.1346	0.1346	0.1154	0.0192	0.0577
3	2.7581	0.9808	1.0000	0.9615	0.8077	0.9615	0.8269	0.8462	0.9423
	2.2064	0.8846	0.9808	0.7692	0.7308	0.9038	0.6731	0.5385	0.9615
	1.7652	0.8654	0.9808	0.6731	0.6923	0.5577	0.4231	0.4423	0.8269
	1.3790	0.4038	0.5577	0.3269	0.3269	0.2885	0.2308	0.1346	0.4808
	1.1032	0.0769	0.2692	0.2115	0.1154	0.0577	0.2308	0.0769	0.3846
	0.0000	0.0000	0.0000	0.0769	0.0192	0.0769	0.1538	0.0577	0.1923

Entries are the proportion of 52 targets presented with indicated size and contrast ratio reported seen by indicated subject.

TABLE 3-2

EXPERIMENTAL DATA - SUBJECTS 3 AND 4

Size (minutes of arc)	Contrast Ratio	Subject 3	Subject 4
20	0.0968	1.0000	0.8846
	0.0774	0.9423	0.7308
	0.0619	0.8654	0.6538
	0.0484	0.5385	0.5000
	0.0387	0.5962	0.5192
	0.0000	0.4808	0.5192
7	0.3920	0.9423	0.6346
	0.3136	0.8270	0.6154
	0.2508	0.7692	0.6346
	0.1960	0.6346	0.5192
	0.1568	0.4615	0.5192
	0.0000	0.5192	0.5769
5	0.6581	0.8654	0.6154
	0.5264	0.8077	0.6923
	0.4212	0.6731	0.5192
	0.3290	0.4615	0.5577
	0.2632	0.2885	0.7115
	0.0000	0.4231	0.5192
3	2.7581	1.0000	0.7692
	2.2064	0.9808	0.5385
	1.7652	0.8462	0.5192
	1.3790	0.7308	0.6154
	1.1032	0.5962	0.7115
	0.0000	0.4038	0.7115

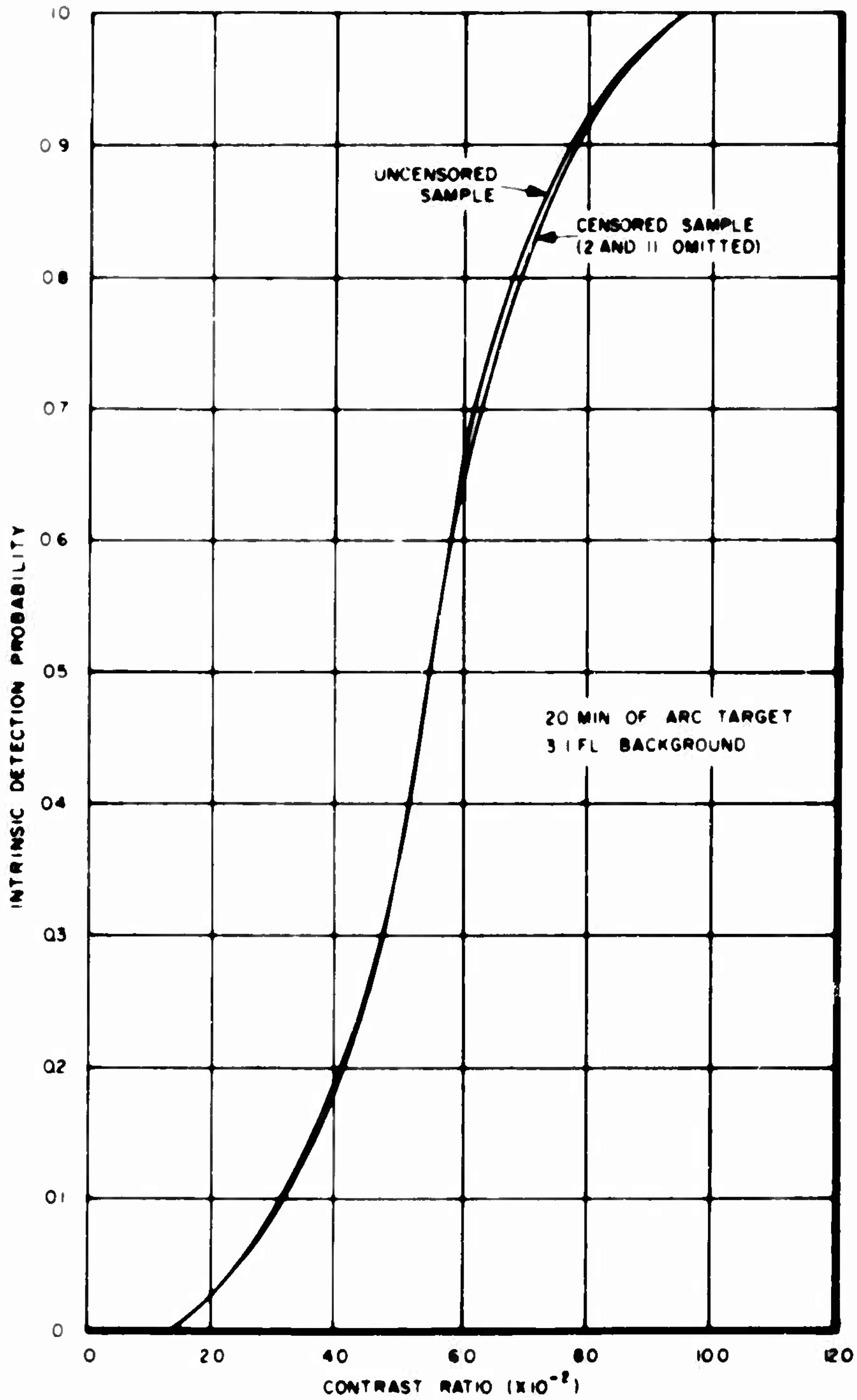


FIGURE 3.1 INTRINSIC DETECTION PROBABILITY VS CONTRAST RATIO
TARGET SIZE 20 MINUTES OF ARC

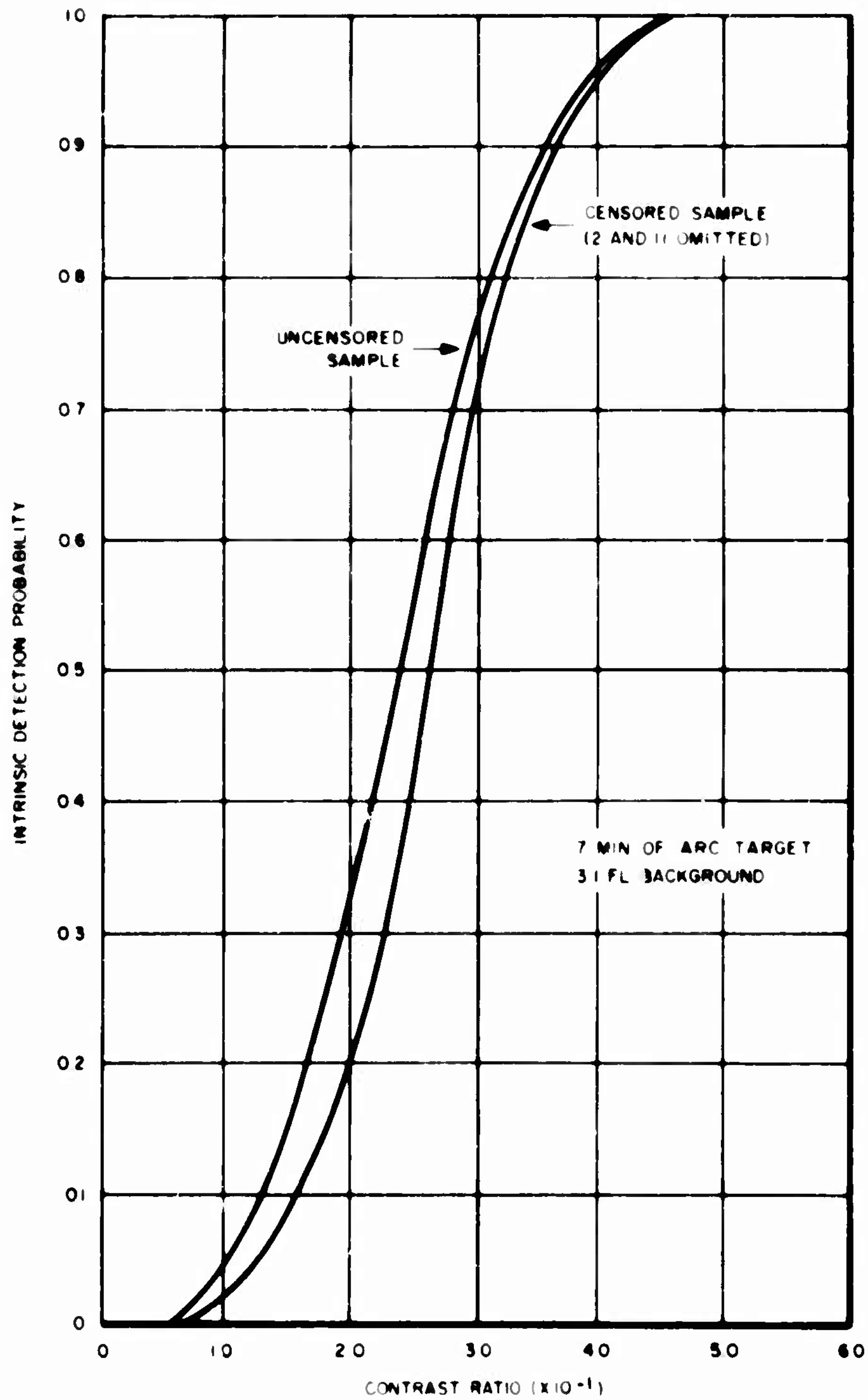


FIGURE 3-2. INTRINSIC DETECTION PROBABILITY VS CONTRAST RATIO
TARGET SIZE = 7 MINUTES OF ARC

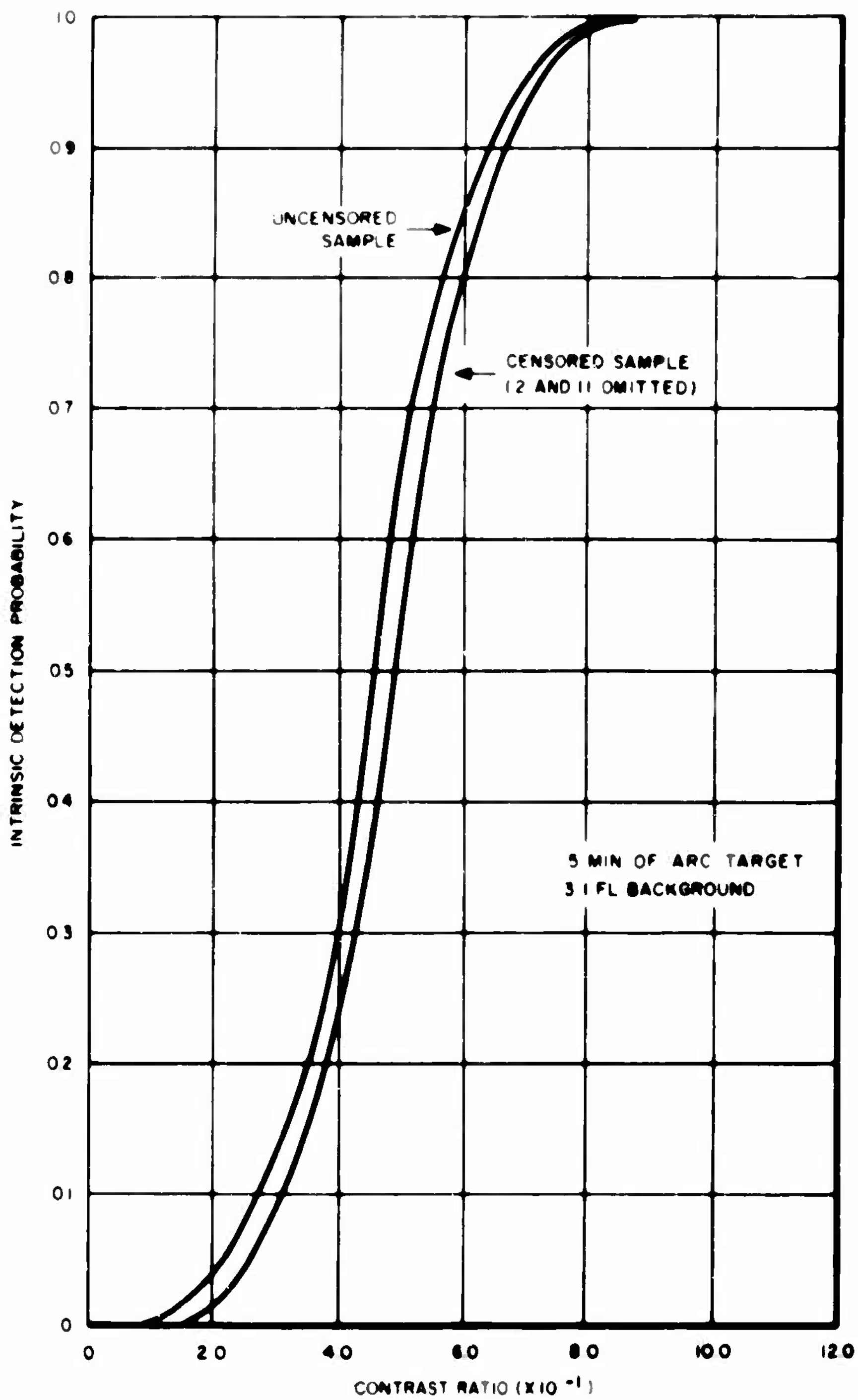


FIGURE 3.3 INTRINSIC DETECTION PROBABILITY VS CONTRAST RATIO
TARGET SIZE 5 MINUTES OF ARC

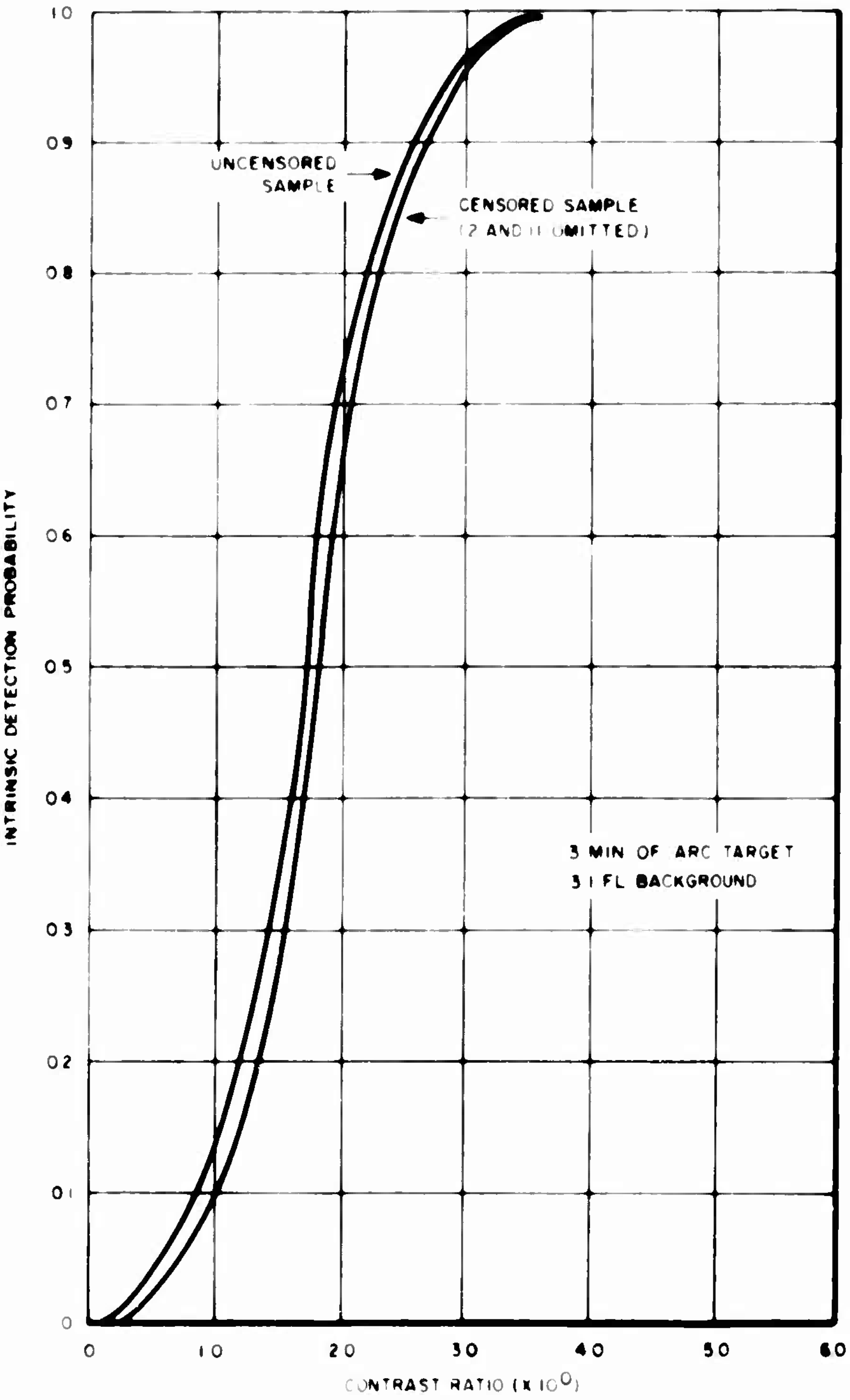


FIGURE 3 4 INTRINSIC DETECTION PROBABILITY VS CONTRAST RATIO
TARGET SIZE 3 MINUTES OF ARC

EXPERIMENT 1A

A. PURPOSE

The purpose of this experiment was to establish the intrinsic threshold curves associated with target detection in the simulator. The experiment differs from Experiment 1 in that uniform circular targets were used.

The intrinsic threshold (PI) is defined as the probability of detecting a fixated target as a function of its size and contrast.

B. METHOD

The experiment employed target size and contrast as independent variables. The following levels were used:

Size (Minutes of Arc at Eye)	Contrast Ratios				
3	0.151	0.220	0.251	0.375	0.450
6	0.039	0.055	0.065	0.100	0.166

Only two sizes were employed because, with uniform circular targets, Ricco's law (Ricco, 1876, Graham, Brown & Mote, 1939) can be applied to determine the detection function for other small sizes.

In addition to the five levels of contrast, there was a sixth level of "no contrast", i.e., no target was placed on the dome in 1/6th of the trials to test for guessing. The contrast ratios are for a 3.1 foot lambert background.

Targets were produced by mounting a block of white Alumina in place of the model in the illuminator ring on the range bed. A circular aperture was placed on the illuminator ring to form a disk image. Size was varied by changing the position of the illuminator ring on the range bed. As before, a one-second exposure time was used.

Fifty trials were used at each contrast level. There were, therefore, 300 trials at each of the two size levels, resulting in a total of 600 trials per subject. The eight subjects used in the earlier experiment were employed here, thereby eliminating a training requirement. Each subject was given four sessions. The sessions were balanced so that the two sizes were alternated over the four sessions. The order of alternation was balanced over subjects as well.

C. RESULTS

The results of the experiment are shown graphically in figures 3-5 and 3-6. The curves were fitted to data points which represent the proportions of detections pooled over subjects at each of the contrast levels. With the well trained subjects, guessing probabilities were both low and homogeneous. The data reduction scheme was the same as that employed in Experiment 1.

D. CONCLUSIONS

The curves obtained in this experiment can be used to obtain intrinsic probability values for Experiment 3.

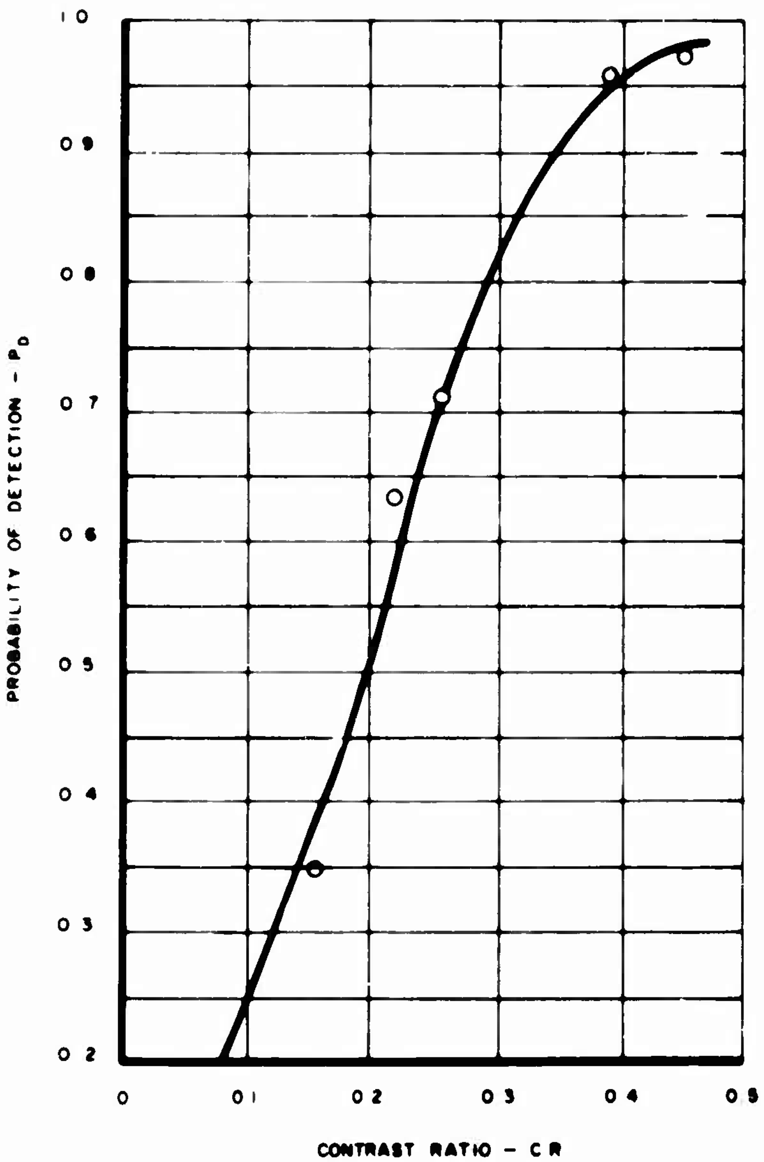


FIGURE 3-5. PROBABILITY OF DETECTION VS CONTRAST RATIO
TARGET SIZE - 3 MINUTES OF ARC

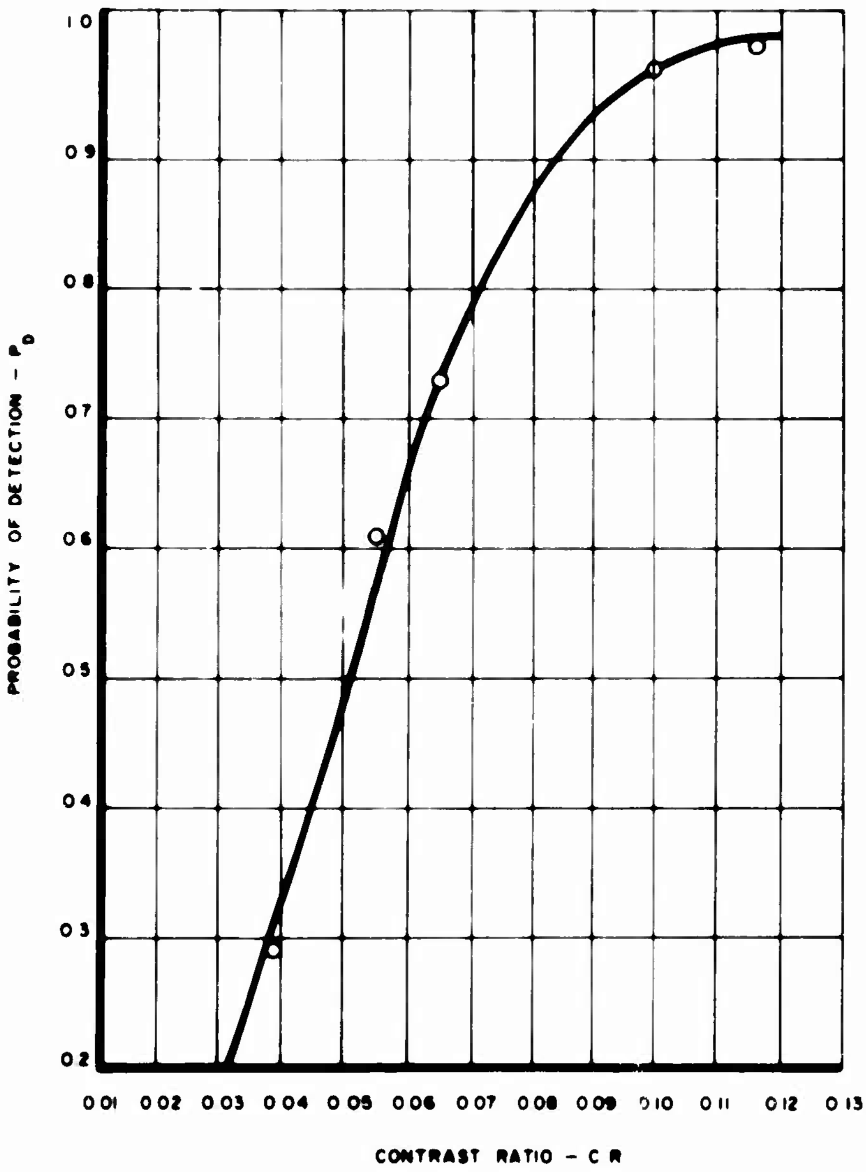


FIGURE 3-6. PROBABILITY OF DETECTION VS CONTRAST RATIO
TARGET SIZE – 6 MINUTES OF ARC

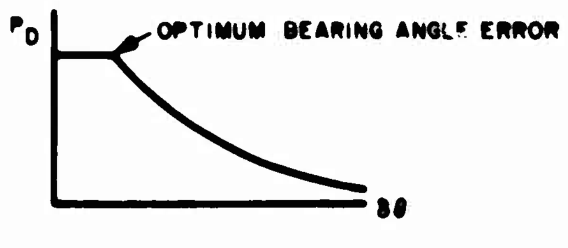
EXPERIMENT 2 - BEARING TOLERANCE STUDY

A. PURPOSE

The purpose of this study was to determine the optimum accuracy or tolerance with which target bearing-angle information should be reported to the pilot. This information can subsequently provide a reference for the design of visual PWI displays.

B. DISCUSSION

Optimum bearing-angle information is defined as that accuracy which permits the best possible visual target-detection performance, but is no more accurate than is necessary to achieve that level of performance. Thus, target-detection performance with optimum bearing-angle information should be no worse than with perfect bearing-angle information. On this basis, it might be expected that detection performance should vary with bearing-angle accuracy as shown in the sketch below.



The accuracy of the bearing-angle information is represented on the abscissa. On the ordinate is some index of subject performance, e.g., time to target detection or detection probability. The optimum bearing-angle tolerance is represented as the region of the inflection of the curve where detection performance reaches some maximum value.

The precise form of the detection curve is a function of how accurately the eye must be centered on the target in order to see it. In the case where the peripheral retina is sensitive to the target, e.g., as with an extremely bright target, the eye need not be centered on the target in order for it to be seen. In this case virtually no search is required and a simple "presence only" warning may be as good as precise information. Theoretically, the performance curve in this case can be straight line, where any warning will result in equally good detection performance.

At the other extreme is the target which requires maximum visual acuity because of its small subtense and low contrast. Since only the central two degrees of the visual field is sensitive to this sort of target, performance will be expected to vary widely with bearing-angle tolerance. Detection will presumably be at a maximum within a certain range of bearing-angle errors and then drop off for larger errors. As errors grow larger, the performance should approach that associated with an unconstrained field of search, as in the case of a presence-only warning for the foveal target.

For experimental purposes, it is important to use a target which can be detected only when its image is on the retinal fovea. However, the target must be virtually 100-percent detectable when it is fixated. Such a target was generated in the F-100A simulator by a red image. This image was produced by placing a Kodak Wratten filter (No. 92) in the filter wheel and adjusting target brightness to an appropriate level. A 20-minute-of-arc target was selected. With this target placed on the simulator dome, it was possible to be sure that the subject was looking in the direction of the target when he detected it and also to be sure that he would detect the target when he was looking at it. In this way both economy of trials and precision of measurement was insured.

C. PROCEDURE

There were three parts to the bearing-angle tolerance study. The first part was a set of pilot experiments in which an attempt was made to train subjects and test the experimental procedures and criteria. The second part was a formal experiment to define the optimum bearing-angle accuracy. This experiment was deficient in certain important respects and therefore another experiment was required. This was the third part of the study.

1. Pilot Runs

The pilot runs were designed to evaluate procedures and to train subjects. The training was necessary, because without it subject performance would change over trials, thereby confounding the experimental results.

Eight non-pilot subjects were employed. These were the same subjects as used in Experiment 1 and were therefore opthalmologically qualified. The subjects had prior experience as operators in an air traffic control situation and were well trained in the concepts of bearing and elevation angles.

As a first step, the brightness of the red target was adjusted so that when the target was placed outside of a one-degree radius of a fixation point it could not be seen by any of the subjects. With the first condition maintained, the brightness was varied until the target could be seen over all of twenty-five presentation trials, when it was within the one-degree radius of the fixation point. In both cases the target was viewed monocularly against a background luminance of 3.1 foot lamberts. A detectable foveal target was thus established.

Each subject was given a session of 75 runs in which the target was placed at various bearing angles in a preprogrammed random order. Five different bearing angles ranging from 10 degrees to the right to 110 degrees to the left were used. These bearing angles were employed at three different elevation angles - 1, 5 and 10 degrees.

Each subject was given a session of 75 trials in which a target was placed, in random order, on any of the possible 15 positions on the dome. Subjects were told the precise bearing and elevation of the target. The performance measure used was time-to-detection of the target. It was assumed that as the subject became skilled in looking in the prescribed direction his performance would show some improvement in the course of the 75 trials. This improvement in performance was expected to be in the form of a shortened average time to detection and a reduction in the variability of the time-to-detection measures.

Inspection of the resulting data made the following conclusions apparent. First, subject performance did not change over the 75 trials. A subsequent test of 25 trials also did not indicate any change in performance in terms of a reduced average search time. Secondly, the resulting data were bimodally distributed. If a target was not detected within 6 seconds it would not be detected in less than 30 seconds. This would indicate that if a target is not detected quickly after perfect bearing and elevation information is given, a subsequent detection does not depend upon the original information. Thus, detections occurring more than 6 seconds after the warning could not be attributed to the bearing-angle information contained in that warning. This means that long-time data does not represent PWI effectiveness but, rather, PWI failure.

As a result of the pilot tests, it was concluded that the criterion of performance should be probability of detection within a five-second period of target exposure. This period was selected because it appears from the pilot runs to represent the duration of the effectiveness of warning information. This result may have implications for repetitive PWI.

In addition, detection-probability data are inherently binomially distributed and with appropriate transforms for counted data lend themselves to parametric analyses.

Another interesting fact encountered during the pilot runs is that detectability of targets at the extreme bearing angles is substantially better than that in the middle of the range of bearing angles. As a matter of fact the curve reflecting average detection time as a function of bearing angle is remarkably similar to the classical bow-shaped curve encountered in studies of serial learning. This suggested that the extremes of the range of bearing angles provided anchoring points for position discrimination. These observations led to the discovery of a shadow on the dome at the far left position. The subject could orient his angle of regard with respect to that shadow. At the far right the straight ahead position apparently provided a sufficient anchoring point. Since the mid-range is an unstructured field, a lower ability to discriminate among positions would be expected. This is very much like stimulus generalization phenomena found elsewhere in experimental psychology.

As a result of these considerations, it was decided that the field in which targets would appear should be rotated 55 degrees to the right so that a 120-degree unstructured field would be available.

2. Bearing-Angle Accuracy Experiment

a. Method

(1) Subjects

The same eight subjects used in the pilot runs were employed in this experiment.

(2) Training

On the basis of the pilot runs, it was assumed that these subjects performed as well as they could possibly perform with a verbal PWI display. However, further training sessions were employed to insure that the subjects were familiar with their tasks and to test the veracity of their responses. Targets were presented for 5-second intervals at each of 15 possible positions on the dome a total of 75 times to each subject. The positions ranged from 50 degrees to the left to 60 degrees to the right of the subject and at 1, 5, or 10 degrees of elevation The targets subtended 20 minutes of arc at the eye and they could be detected with foveal vision only Subjects were given perfect position information on all trials

(3) Experiment Proper

The same stimulus conditions were used as in the training sessions. Three elevation angles were employed and were always reported correctly to the subject These were 1, 5, and 10 degrees of elevation as before. Five nominal bearing angles were employed These were 50 and 12 degrees to the left of the subject's straight ahead or primary position and 10, 30, and 60 degrees to the right of his primary eye position The target was actually presented at one of five different azimuthal distances from the reported bearing angle. These distances had been selected during the pilot runs These were 3, 7, 11, 15 and 19 degrees away from each nominal bearing angle.

Each experimental session consisted of one trial of each combination of elevation angle, nominal bearing angle, and bearing angle error or 3 x 5 x 5 = 75 combinations in all. There were ten sessions per subject which resulted in 750 trials per subject The experiment was scheduled to last ten days, so that experimental days could be treated as blocks. Subjects were randomized as to the time of day in which they participated in the experiment in order to counterbalance fatigue

The exact experimental procedure was as follows The subject was read a prepared set of instructions. He was then told that he would be verbally given a target position in terms of bearing and elevation angle In the training session, he was told that the target would actually appear at the position indicated In the experimental sessions proper he was told that some error would be introduced. In both cases the subject was told that target exposure time would be limited to five seconds Further, he was told that immediately after receiving the verbal information he would hear a tone in his headset. Upon hearing the tone, but not before, he commenced search for the target. On finding the target, he depressed the response button located in the cockpit A second tone signaled the end of the target-search interval. The subject stopped searching and looked straight ahead.

On seven trials in each session, the experimenter checked the veracity of the subject as follows: a shutter override button was provided on the experimental console When this button was depressed, the shutter remained open after the timer ran down (Note: the shutter override button did not affect the second momentary tone or the inability of the subject to actuate the response light after the target exposure time). The experimenter depressed the shutter override button on four of the seven veracity check runs, selected at random in each session During each veracity check trial the experimenter asked the subject if the target was still on the dome. He noted the correctness of the subject's response in the column provided on his run sheet, released the override button, and proceeded to the next trial.

After each experimental session, the results of the veracity check trials were inspected. It was intended that if the results of the veracity checks raised doubts about the usefulness of the data the subject would be replaced. This was never found to be necessary.

b. Results

The number of "yes" responses was collected for each experimental condition for each subject. Table 3-3 shows the number of "yes" responses given by each subject when the target was at any one of the actual bearing angles, nominal bearing angles, and actual elevation angles. These data are further summarized in table 3-4 where the proportion of "yes" responses given by each subject is shown for each bearing angle error. Table 3-5 shows the proportion of "yes" responses made by all subjects at each bearing angle error at each of the elevation angles. Table 3-6 shows the proportion of "yes" responses with respect to bearing angle error when the data are pooled over subjects, elevation angles, and nominal bearing angles.

Figure 3-7 shows the probability of detection of targets as a function of bearing angle error. The relevant data points are those listed as belonging to the "main experiment". Secondary data were also collected and are discussed below.

Under the assumption that experimental trials are independent an analysis of variance was performed on the data. Since that data is "counted", the angular transform was employed to stabilize the variance. The summary of the analysis of variance is shown in table 3-7.

It will be noted in the table that all main effects are significant with the exception of nominal bearing angle. All second-order interactions are significant with the exception of that between nominal bearing angle and subjects. Thus, the model of subject response to bearing-angle errors generated is quite complicated and difficult to apply to any given set of conditions.

c. Discussion of Results

Inspection of the data shown in figure 3-7 does not reveal a break point such as that anticipated in the introductory discussion of this experiment. However, performance of the subjects when the bearing angle error was 3 degrees was substantially lower than their performance with zero error on the pilot runs. Although the pilot run performance data were in terms of time-to-detection, it was possible to relate that data to the same terms as used in the experiment by tabulating numbers of detections within five seconds. The mean detection

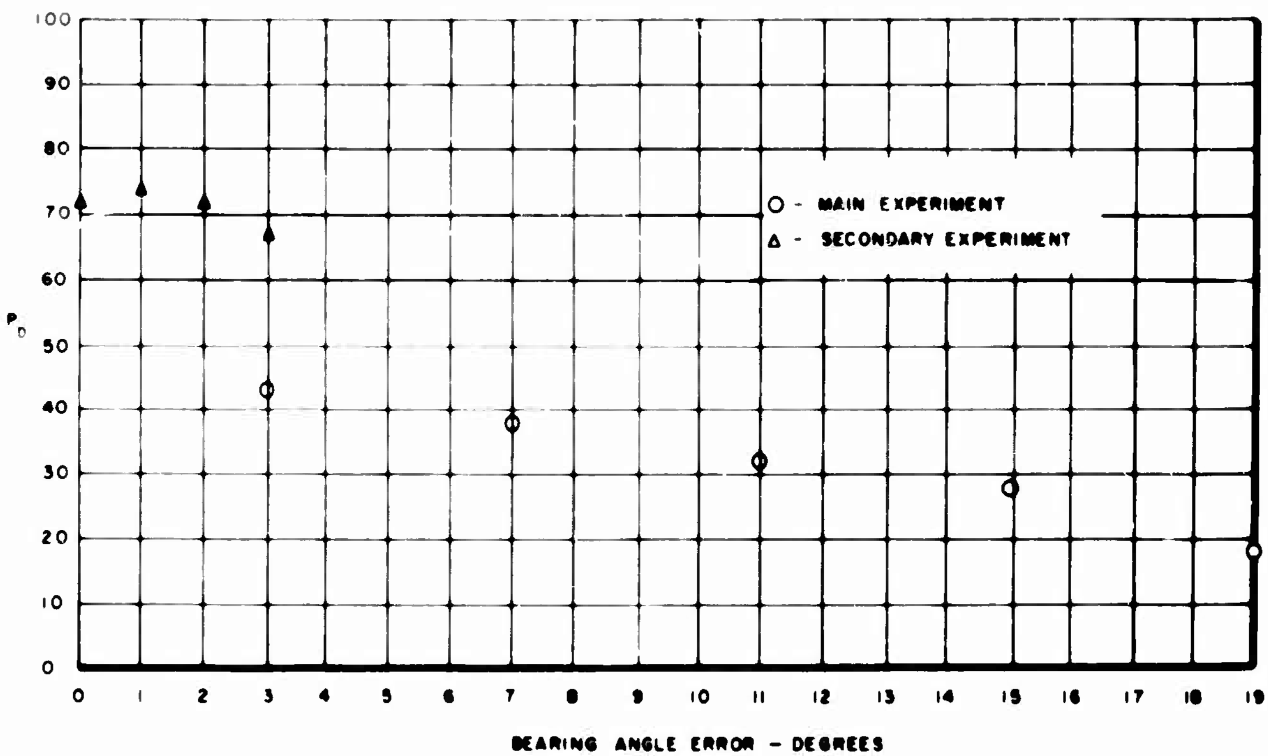


FIGURE 3-7 PROBABILITY OF DETECTION VS BEARING ANGLE ERROR

probability for all subjects in the pilot runs was 0.74, whereas in the experiment it was 0.43 with a 3-degree bearing-angle error. It was therefore supposed that the break point defining the optimum bearing-angle error lay between zero and 3 degrees. Consequently, additional data were obtained between zero and 3 degrees, using the same procedures outlined above.

d. Secondary Data: Results and Discussion

Utilizing the same procedures as those employed in the main experiment, a secondary experiment was conducted in which bearing-angle errors of 0, 1, 2 and 3 degrees were substituted for those used previously. The results of this experiment are summarized with respect to bearing angle error in table 3-8. They are also shown in figure 3-7. It will be noted that performance was uniformly better for all bearing-angle errors, with a marked improvement at 3 degrees over that in the main experiment, i.e., 0.67 probability of detection as opposed to 0.43 at the same bearing-angle error.

There appeared to be only one plausible explanation for this difference in performance. The performance of subjects at different bearing-angle errors is influenced by their exposure to other bearing-angle errors. Thus, if a subject experiences wide discrepancies between a particular nominal bearing angle and the one at which he actually discovers a target, it is likely that on ensuing trials he will search widely for the target even if it is in fact not as far from the nominal angle. His performance should therefore be influenced by the distribution of errors utilized in a given session. This conclusion vitiates the meaningfulness and validity of the analysis of variance and may account for the complexity of the model generated thereby. Therefore, it was decided that another experimental design should be employed. This is the subject of the third part of this experiment.

3. Second Bearing-Angle-Tolerance Experiment

(a) Method

Four of the eight subjects previously employed were used in this experiment.

The same physical procedures were employed in this experiment as in the first experiment. The instructions were modified in that subjects were told to utilize whatever reference points in the cockpit that they could in order to look more accurately in a given direction, and thereby possibly reduce subject differences.

The same elevation angles were used as before and always reported correctly to the subject. However, the bearing-angle information was reported differently to the subject than previously. Instead of reporting the same nominal bearing-angle information from trial to trial, the target was placed at one of a large number of nominal bearing angles and the reported bearing angle was obtained by adding or subtracting a predetermined error. This was considered to be an improvement in basic procedure.

Fundamental to the present approach is a different concept of bearing-angle error. Previously fixed bearing-angle errors were employed in a manner such that all error magnitudes were equally represented in each session. This may be considered to be a sample from a rectangular distribution of errors. Actually this is somewhat artificial, since with real equipment the errors generally have a Gaussian distribution about a mean zero error. Consequently, sets of samples of normal distributions of errors characterized by their standard deviations and zero mean were generated. This was done as follows: The volume "Table of a Million Random Numbers and One Hundred Thousand Standard Normal Deviates" (Rand Corp.) contains a table comprised of numbers which are a large sample from a normal distribution. The standard deviation of these numbers is one and the mean is zero. Six lists of 105 numbers were compiled at random from this table. These lists were used to generate six different samples of bearing-angle errors. These six, plus $\sigma = 0$, provided seven samples for the experiment. The parent population of these samples had σ's of 0, 1, 5, 3, 4. 5, 6, 9 and 12 degrees and mean zero degrees. For $\sigma = 0$ there is no error and bearing angles reported to the subject were the actual bearing angles. For $\sigma \neq 0$, the values in the lists taken from the table were multiplied by the value of σ assigned to the given list.

A method of stratified sampling was applied in this experiment because of the lack of independence of trials having different bearing-angle errors. Thus, each session was comprised only of trials drawn from a single list. The different σ's were therefore used in separate sessions.

Again, because of the possible influence of one distribution on another, two of the subjects had a $\sigma = 0^{\circ}$ distribution on their first trial and the other two subjects were first exposed to $\sigma = 12^{\circ}$.

A counterbalanced design was used in that subjects had equal numbers of trials in mornings and in afternoons. In all, each subject had 105 trials for each bearing-angle error distribution. Thus, a total of 2940 trials was employed in this experiment.

(b) Results and Conclusions

The results of the experiment are summarized in figure 3-8. When subjects are presented with the $\sigma = 0^{\circ}$ sample population first, a break point exists in the data when σ is approximately 1. 5 degrees. This break point defines the optimum bearing-angle tolerance. The differences between the two subject conditions may be attributed to the lack of independence of sessions. Those who first experienced wide errors tended to expect wide errors and therefore may have been less trusting in the information they received. They appeared to be more careless in their use of the information. The other two subjects may have been more trusting and therefore more careful.

A relative performance plot was also made (figure 3-9). Here each subject's performance at $\sigma = 0^{\circ}$ was graded arbitrarily as 1.0 and his other scores proportionally represented i.e. each P_D (Probability of Detection) was divided by the subject's performance at $\sigma = 0^{\circ}$. The results were then averaged again for the two pairs of subjects. There is roughly a 3:1 improvement with accurate bearing-angle information. This result is consistent with flight test data reported by Howell (1957) in the TDC report on daytime conspicuity of transport aircraft.

TABLE 3-3

NUMBER OF "YES" RESPONSES OUT OF 10 PRESENTATIONS AT EACH LOCATION FOR EACH SUBJECT

Elevation = 1°		Subjects							
Nominal Bearing (degrees)	Bearing Error (degrees)	1	2	3	4	5	6	7	8
10 Right	3	5	5	6	5	6	9	6	9
	7	4	5	9	7	3	9	8	4
	11	0	3	10	7	6	7	7	5
	15	3	1	6	2	1	5	3	7
	19	1	1	7	2	4	1	3	1
12 Left	3	1	7	8	6	4	4	6	9
	7	3	1	6	5	5	7	7	5
	11	2	0	8	7	4	7	8	6
	15	4	0	8	5	2	7	7	6
	19	1	0	2	2	1	4	8	4
50 Left	3	3	0	7	3	3	5	6	4
	7	4	4	6	7	4	6	6	7
	11	5	7	7	3	4	7	7	9
	15	2	4	6	4	4	4	9	5
	19	1	2	4	3	7	7	6	3
30 Right	3	2	6	5	4	3	5	4	7
	7	2	2	7	5	1	7	4	5
	11	0	0	6	8	0	6	6	4
	15	7	1	5	5	3	3	4	3
	19	0	0	8	6	2	3	3	2
60 Right	3	6	6	8	7	2	7	5	5
	7	3	1	6	4	6	8	4	3
	11	1	2	6	3	3	8	3	2
	15	3	0	4	4	4	6	3	5
	19	3	0	6	2	3	5	6	1

Elevation = 5°		Subjects							
Nominal Bearing (degrees)	Bearing Error (degrees)	1	2	3	4	5	6	7	8
10 Right	3	4	3	8	3	4	5	5	4
	7	3	0	8	4	1	5	5	2
	11	3	2	9	3	0	7	6	0
	15	0	1	7	1	1	6	6	1
	19	3	0	2	0	1	3	1	1
12 Left	3	1	4	6	5	4	5	6	5
	7	2	5	6	8	4	3	4	3
	11	0	1	5	2	3	2	4	2
	15	2	1	2	1	0	6	2	4
	19	1	1	2	1	0	2	3	2
50 Left	3	3	1	6	4	1	5	5	7
	7	4	0	7	7	2	6	1	8
	11	2	1	7	1	2	1	5	1
	15	2	1	5	3	2	5	4	4
	19	2	0	3	2	1	0	3	2
30 Right	3	0	3	5	3	3	6	3	3
	7	1	0	7	2	1	2	2	2
	11	3	0	5	3	4	3	4	3
	15	3	1	4	1	1	6	4	4
	19	3	0	0	0	3	5	2	0
60 Right	3	5	1	7	7	2	5	4	2
	7	3	0	7	3	1	5	1	0
	11	3	1	5	4	3	5	1	0
	15	1	0	5	1	1	4	1	0
	19	3	0	6	3	1	3	1	5

Elevation = 10°		Subjects							
Nominal Bearing (degrees)	Bearing Error (degrees)	1	2	3	4	5	6	7	8
10 Right	3	6	5	5	4	4	6	4	2
	7	2	0	6	3	1	2	3	2
	11	0	2	5	4	1	7	3	2
	15	1	0	5	1	5	3	2	2
	19	1	0	1	1	4	1	0	0
12 Left	3	5	5	7	5	2	5	5	4
	7	5	4	6	7	3	5	3	0
	11	0	0	4	1	1	1	4	2
	15	4	1	4	1	5	4	2	1
	19	2	0	2	3	4	1	1	0
50 Left	3	2	1	5	4	1	3	1	2
	7	2	0	4	2	2	3	5	2
	11	1	0	1	1	1	1	5	0
	15	3	0	2	1	3	2	0	2
	19	1	0	6	3	1	0	0	0
30 Right	3	1	1	4	2	2	7	4	4
	7	2	2	5	2	5	6	3	1
	11	0	0	4	6	1	5	3	1
	15	6	0	3	2	1	3	1	1
	19	2	1	0	0	1	1	1	1
60 Right	3	6	4	6	6	1	6	1	1
	7	1	5	7	6	3	4	1	2
	11	4	3	7	4	2	7	2	2
	15	1	1	1	2	0	5	2	0
	19	1	0	3	2	5	3	3	0

TABLE 3-4

PROPORTION OF DETECTIONS - POOLED OVER NOMINAL ELEVATION AND BEARING ANGLES

Subject	Bearing Angle Error (degrees)	Proportion Detected	Subject	Bearing Angle Error (degrees)	Proportion Detected
1	3	.328	5	3	.291
	7	.287		7	.301
	11	148		11	.232
	15	.281		15	.220
	19	.194		19	.254
2	3	.338	6	3	.552
	7	.170		7	.520
	11	.137		11	.486
	15	.091		15	.402
	19	.048		19	.254
3	3	.612	7	3	.433
	7	.638		7	.382
	11	.593		11	.454
	15	.447		15	.331
	19	.333		19	.265
4	3	.450	8	3	.457
	7	.480		7	.298
	11	.382		11	.249
	15	.238		15	.289
	19	.200		19	.143

TABLE 3-5

PROPORTION OF DETECTIONS - POOLED OVER SUBJECTS AND NOMINAL BEARING ANGLE

Elevation Angle (degrees)	Bearing Angle Error (degrees)	Proportion Detected
1	3	.518
	7	.499
	11	.468
	15	.408
	19	.305
5	3	.404
	7	.330
	11	.283
	15	.258
	19	.175
10	3	.373
	7	.315
	11	.235
	15	.208
	19	.138

TABLE 3-6

PROPORTION OF DETECTIONS - POOLED OVER NOMINAL BEARING AND ELEVATION ANGLES AND SUBJECTS

Bearing Angle Error (degrees)	Proportion Detected
3	.431
7	.380
11	.325
15	.287
19	.184

TABLE 3-7

ANALYSIS OF VARIANCE SUMMARY

Effect	D.F	S.S	F.	Significant at 5%
Main Effects:				
Nominal Bearing Angle	4	1.3933	0.5690	No
Nominal Elevation Angle	2	18.0143	14.6577	Yes
Bearing Angle Error	4	17.6889	9.7492	Yes
Subject	7	37.2533	8.0769	Yes
Two-Factor Interactions				
(Nominal Bearing Angle) x (Nominal Elevation Angle)	8	2.6382	2.7879	Yes
(Nominal Bearing Angle) x (Bearing Angle Error)	16	4.7303	2.4994	Yes
(Nominal Bearing Angle) x (Subject)	28	6.0546	1.8280	Yes
(Nominal Elevation Angle) x (Bearing Angle Error)	8	0.5321	0.5623	No
(Nominal Elevation Angle) x (Subject)	14	5.6288	3.3990	Yes
(Bearing Angle Error) x (Subject)	28	7.7111	2.3282	Yes
Pooled Error	480	56.7779		
	599			

TABLE 3-8

SECONDARY EXPERIMENT DATA

Bearing Angle Error (degrees)	Frequency of Detection	Trials
0	.72	108
1	.74	111
2	.72	108
3	.67	100

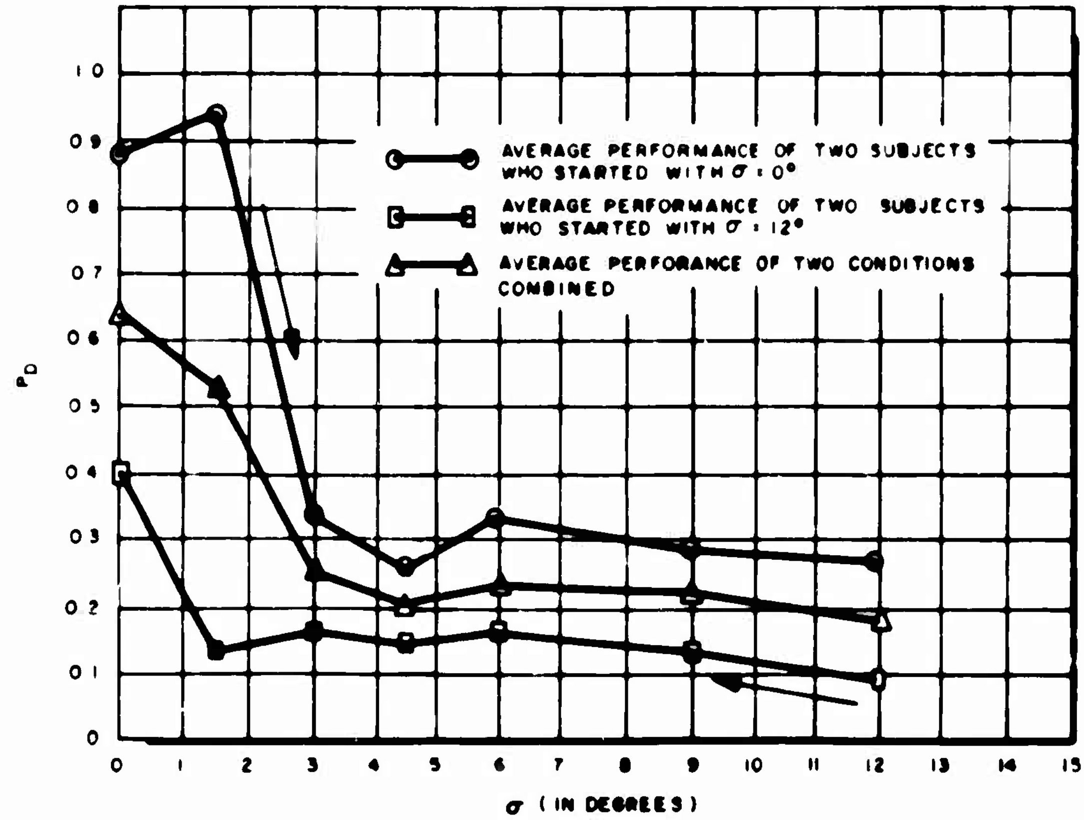


FIGURE 3-8. PROBABILITY OF DETECTION VS STANDARD DEVIATION OF THE BEARING ANGLE ERROR (σ)

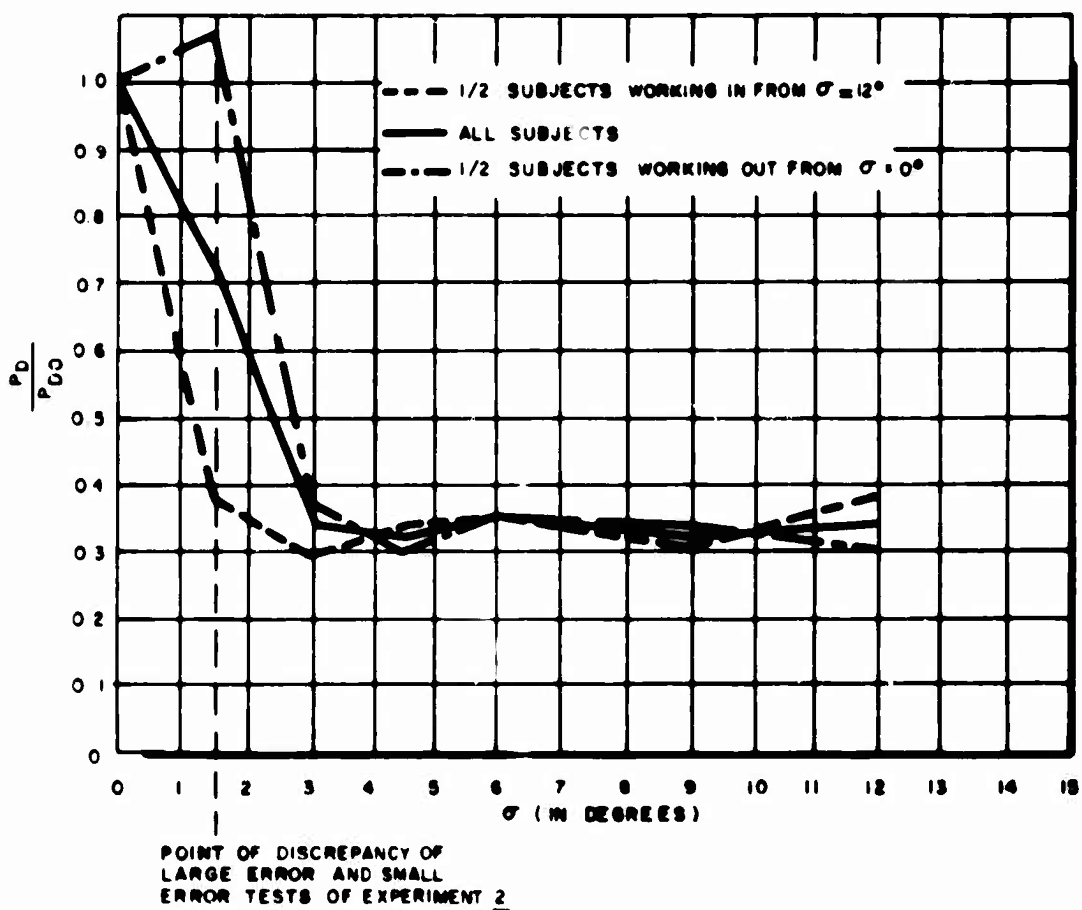


FIGURE 3-9. EFFECT OF BEARING TOLERANCE ON RELATIVE PERFORMANCE OF SUBJECTS REFERENCED TO σ = 0 PERFORMANCE - POOLED DATA

EXPERIMENT 3 - SEARCH TEST

The purpose of Experiment 3 was to assess the usefulness of various levels of PWI, given verbally, in the visual detection of intruder aircraft.

A. DISCUSSION

The theoretical limit of a v... collision-prevention system is the sensitivity of the human eye. If an intruder lies beyond this limit it will remain unobserved and the pilot will be unable to take action. If, however, the target is within the range of sensitivity of the eye, then the information presented to the pilot must make it possible for him to see the intruder in order for it to be effective. The question to which this study is addressed is how effective PWI is in making it possible for the pilot to detect intruders which are within the range of sensitivity of his eye.

In order to answer this question, use was made of an approach developed earlier in this program. The approach was to utilize the intrinsic detectability of a target as the independent variable and to measure the probability of detection at each PWI level as the dependent variable.

B. METHOD

The experimental variables which were systematically controlled were

- Intrinsic detection probability
- PWI level
- Target position
- Time interval between presentation of targets.

The intrinsic probability values employed were 0.00, 0.95, 0.88, and 0.70. Pilot tests showed that targets less detectable than 0.70, when fixated, were practically never found by searching observers. The intrinsic probability values were all obtained by selecting the appropriate target brightness for targets with diameters subtending an angle of 3 minutes of arc at the eye. This was based on Experiment 1 data. Dome brightness was 3.1 foot-lamberts. To maintain calibration, target and dome brightness were measured after every two sessions.

The levels of PWI employed were as follows:

1. Passive Observer

In this case the pilot received no warning information on any kind. He served as a lookout for intruding aircraft after the manner of a copilot in a region of heavy traffic.

2. No PWI with Workload

In this condition the subject was required to detect and report intruders while executing a normal IFR flight plan. He made use of VOR airways while enroute under ATC. A sample flight plan will be found in Appendix A. Whenever workload was applied, approximately equivalent flight plans were employed. In all, there were four different flight plans. No warning of intruder presence was given. This condition was employed to obtain a lower bound of the set of possible relations between intrinsic probability and search probability of detection.

3. Warning Only

The procedure here was the same as that in the "No PWI" case except that a tone was sounded over the pilot's headset whenever an intruder was presented. No position information was given. This condition was included to assess the worth of the so-called proximity warning device.

4. Azimuth Information

The subject executed a flight plan in this condition similar to that employed in the two foregoing conditions. He was warned of intruder presence by a tone over his headphones and also was told the exact relative bearing of the intruder.

5. Azimuth and Elevation Information

The procedure was the same as that in the azimuth information case except that the pilot was given elevation information as well as relative bearing information.

Target position was varied, both in elevation and azimuth. Nine degrees of elevation angle were employed, from one to ten degrees above the horizon.

This interval was divided into three blocks of three degrees each. Elevation angles were randomized with an equal number of trials in each block for each subject. Higher elevations were not employed because the intruding aircraft would be quite close and probably flying by. A coverage of one hundred ten degrees in azimuth was employed from 280° through 0° to 30°. This interval was divided into ten blocks of eleven degrees each. The same randomization procedure was employed with respect to azimuth angle as elevation angle.

The interval between target presentations was varied randomly in accordance with the following frequency distribution:

Time between presentations (minutes)	Frequency of presentation in each session
0.50	10
1.25	8
2.00	6
3.00	4
12.00	2

Ten seconds were allowed for each presentation. Prior to the experiment, tapes of timed tones were prepared. The periods between the tones corresponded to those given above. On signal from a tone the experimenter readied himself to present the target. On the next tone signal he presented the target. The intervals between target presentations were ordered randomly and were represented in proportions appropr ate to the frequency distribution. Thirty two presentations were given in each session. The duration of a session was 1.5 hours. Four sessions were held in a working day.

Subjects were six pilots stationed at NAFEC. They were screened on an Ortho-Rator and found to have 20/20 visual acuity and normal phorias.

Since there were five levels of PWI (including the passive observer and the no-warning cases), four levels of intrinsic probability, and six subjects, a 5x4x6 factorial design was employed. Factors such as target position and time of day of session wei counter-balanced to eliminate confounding effects. Since there were 32 trials per session and 120 sessions were held, a total of 3840 trials were conducted.

Each session was concerned with only one level of PWI. In each session all four intrinsic probability levels were presented for eight trials in random order. One pilot served in each session. Assignment of pilots to sessions followed a balanced schedule.

Prior to running the experiment the pilots were trained to fly the F-100A to the satisfaction of a jury of competent simulator pilots.

The experimenter worked from a run sheet which listed target position in bearing and elevation and target contrast for each trial. Controls on a console allowed the experimenter to set the conditions for the trials.

A switch to activate the warning tone, when required, was also provided. On signal from the tape recorder the experimenter opened the shutter which exposed the target for 10 seconds at the prescribed position. If the warning tone switch was in the "ON" position, activating the shutter also sounded the warning tone.

Prior to each session, the subject was briefed on his flight plan when a flight plan was required. He was given ten minutes to get his aircraft to altitude and set up his desired course. At the same time, he was becoming adapted to the dome luminance.

The subject was told that he was to search for and locate the intruder aircraft. Upon finding an intruder he was instructed to press a response button. His pressing of the button was indicated to the experimenter by a light on the console. In all cases but that of passive observer, the pilot was also instructed to fly the simulator as well as he could in accordance with the flight plan.

The number of positive responses to the presence of an intruder was tabulated by the experimenter on the run sheet. In addition, the performance of the pilot in executing his flight plan was evaluated by a flight simulator expert.

C. RESULTS

The number of positive responses, i.e. a detection under each condition of the experiment and for each subject, is shown in table 3-9. Table 3-10 shows mean probabilities of detection at each PWI level for all subjects. A Friedman two-way analysis of variance shows that PWI levels differ significantly, $P < 0.001$.

Figure 3-10 shows the mean probabilities of detection at each PWI level as a function of intrinsic probability for all subjects. The lines represent least squares fits of search versus intrinsic probabilities for all subjects to the function $P_s = aP_i^n$. This empirical equation was selected because the arrangement of the average data points over subjects appears to approximate a straight line (or power function) when plotted on log-log paper. The functions appear as straight lines in figure 3-10 because they are plotted on logarithmic scales. The actual data points averaged for all subjects are also shown.

It is evident in the curves and tables that detection performance improves with degree of PWI sophistication. Performance also improves as a monotonic function of intrinsic probability level. Subjects obviously differ in detection performance. Probability of detection for individual subjects at each PWI level are shown in table 3-11. Again subject differences are apparent.

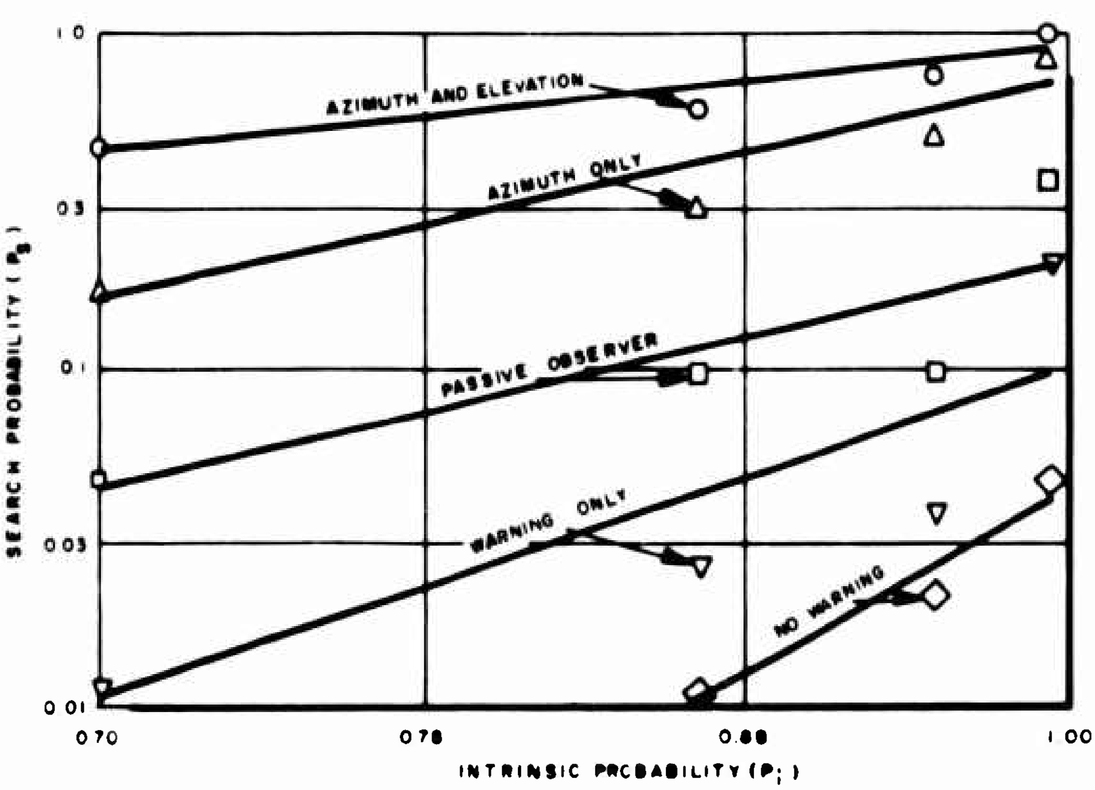


FIGURE 3-10. MEAN PROBABILITY OF DETECTION

Table 3-12 provides a breakdown of proportion of detections as a function of bearing and elevation-angle segments. The bearing-angle segments were set at 21 degrees and elevation-angle segments at 3 degrees. The proportions of detections in each of these horizontal and vertical angular segments was computed by dividing the number of positive responses in each segment by the total number of presentations in that segment. There are no marked blind regions in which detection performance departs significantly from average performance as a function of bearing angle. The same is true for elevation angle. Inspection of the data indicates that performance is sufficiently the same from position to position to make more detailed analysis superfluous

D. CONCLUSIONS

The data clearly indicate that performance varies significantly with PWI level. A working pilot without PWI did most poorly. A working pilot with a warning did better, but not as well as a passive observer or lookout. It must be remembered, however, that the passive observer in the tests was aware that intruders would appear. When precise bearing-angle information is provided there is a dramatic improvement in performance, as measured by increment in probability of detection. The addition of elevation information further improves detection probability, to values approaching those obtained under fixation.

TABLE 3-9

TOTAL NUMBER OF DETECTIONS FOR
EACH EXPERIMENTAL CONDITION

PWI Level	Intrinsic Probability	Subject					
		1	2	3	4	5	6
No Warning	0.999	2	2	0	3	1	1
	0.949	2	0	0	0	0	2
	0.877	1	0	0	0	1	0
	0.702	0	0	0	0	0	0
Passive Observer	0.999	5	14	15	12	6	17
	0.949	3	3	5	4	0	4
	0.877	4	2	3	6	2	2
	0.702	5	0	0	1	0	3
Warning Only	0.999	12	3	9	2	9	5
	0.949	2	0	3	0	0	2
	0.877	1	0	1	0	3	0
	0.702	0	0	2	0	0	0
Azimuth Only	0.999	29	27	31	25	27	23
	0.949	26	9	22	11	13	14
	0.877	15	6	16	6	6	10
	0.702	11	2	10	1	5	6
Azimuth & Elevation	0.999	32	32	31	27	31	29
	0.949	30	24	31	13	20	25
	0.877	29	9	28	9	16	21
	0.702	24	8	23	7	7	17

TABLE 3-10

MEAN FREQUENCY OF DETECTION
AS A FUNCTION OF INTRINSIC PROBABILITY (P_I)

PWI Level	Intrinsic Probability			
	.702	.877	.949	.999
No Warning	0	.010	.021	.047
Passive Observer	.047	.099	.099	.35
Warning Only	.010	.026	.036	.208
Azimuth Only	.182	.307	.495	.844
Azimuth and Elevation	.448	.583	.745	.948

TABLE 3-11

MEAN FREQUENCY OF DETECTION BY SUBJECTS

PWI Level	Subject					
	1	2	3	4	5	6
No Warning	.038	.016	0	.023	.016	.023
Passive Observer	.133	.148	.180	.180	.062	.203
Warning Only	.117	.023	.117	.016	.094	.055
Azimuth Only	.633	.344	.617	.336	.398	.414
Azimuth and Elevation	.898	.570	.883	.438	.578	.719

TABLE 3-12

FREQUENCIES OF DETECTION AS A FUNCTION OF
BEARING AND ELEVATION ANGLE

AZIMUTH*	280-302°				303-324°				325-346°				347-8°				9-30°			
PWI \ P_I	.702	.877	.949	.999	.702	.877	.949	.999	.702	.877	.949	.999	.702	.877	.949	.999	.702	.877	.949	.999
1	0	0	.067	.067	0	0	.024	.024	0	.017	.017	.050	0	0	0	.042	0	.083	0	.083
2	.100	.133	.067	.367	.056	.083	.111	.278	.033	.100	.100	.400	.041	.104	.033	.354	.021	.083	.125	.354
3	0	.067	.067	.200	0	.024	.024	.167	.021	0	0	.271	.024	.048	.024	.214	0	0	.067	.167
4	.229	.271	.550	.792	.222	.333	.500	.889	.190	.167	.524	.833	.167	.389	.472	.778	.067	.400	.500	.933
5	.500	.583	.667	1.000	.315	.648	.778	.981	.611	.630	.593	.981	.367	.400	.800	.867	.433	.567	.800	.967

ELEVATION*	1-4°				5-7°				8-10°			
PWI \ P_I	.702	.877	.949	.999	.702	.877	.949	.999	.702	.877	.949	.999
1	0	0	.014	.042	0	.019	.037	.019	0	.015	.015	.061
2	.011	.133	.089	.300	.028	.028	.167	.250	.091	.212	.556	.485
3	.013	.038	.026	.256	.014	.014	.056	.181	0	.024	.024	.167
4	.205	.397	.295	.897	.139	.278	.528	.778	.261	.214	.571	.833
5	.452	.536	.714	.964	.444	.583	.722	.944	.458	.639	.750	.958

NUMBER OF REPLICATIONS

AZIMUTH \ PWI	1	2	3	4	5
280-302°	30	30	30	48	24
303-324°	42	36	42	36	54
325-346°	60	30	48	42	54
374-8°	48	48	42	36	30
9-30°	12	48	30	30	30

ELEVATION \ PWI	1	2	3	4	5
1-4°	72	90	78	78	84
5-7°	54	36	72	72	36
8-10°	66	66	42	42	72

PWI	DESCRIPTION
1:	NO WARNING
2:	PASSIVE OBSERVER
3:	WARNING ONLY
4:	AZIMUTH ONLY
5:	AZIMUTH & ELEVATION

P_I = INTRINSIC PROBABILITY

*ENTRIES ARE FREQUENCIES (NO. POSITIVE RESPONSES/NO. TRIALS)

EXPERIMENT 4 - EVALUATION STUDY

A. PURPOSE

The purpose of this experiment was to determine the effect of PWI on the pilot's ability to discriminate between intruder aircraft on collision and non-collision courses.

B. DISCUSSION

PWI was shown in Experiment 3 to be capable of enhancing the range at which aircraft can be detected. It was found that for foveally detectable targets "Warning only PWI" yields no improvement of probability of detection at any range as compared to present day "see and be seen" practices. On the other hand, a marked improvement in probability of detection occurs when azimuth or azimuth and elevation information is provided. The mere improvement of detection range, however, is not an adequate criterion for a full evaluation of PWI. It is conceivable that early detection will not lead to improvement in the ability of a pilot to discriminate among levels of threats. Moreover, there is the distinct possibility that earlier detection will result in an incorrect decision which may lead to inappropriate or unneccessary maneuvers.

There are two major variables which determine the pilot's ability to evaluate the threat posed by an intruder. These are

- the range at which the intruder is first detected
- the time available from initial detection to the time at which a decision must be made.

Therefore, two measures of subject performance were required. These were

- his ability to discriminate among levels of threats
- the speed with which the subject made a correct decision, as a function of acquisition range and available observation time.

Four pilots served as subjects. Although their flying ability per se was not utilized in the present study, their training and experience in evaluating collision threats of aircraft was a necessary subject prerequisite. The subject sat in the cockpit of the F-100 simulator but did not fly the simulator. His only task was to judge and report whether a collision threat was posed by the intruder aircraft. The subject was told the bearing angle and elevation angle of the intruder before it was presented, so that he could fixate on that area. The intruder was then presented and, when the subject reported that he saw it, it was moved along a predetermined course.

A continuous response record of the subject's judgments of the path of the intruder was obtained. Three response switches were provided and the subject was required to manipulate these switches throughout each run. He was to indicate "UNDECIDED" as soon as he saw the intruder. If the subject thought that the intruder would collide with his own plane, he was to move the switch to the position marked "COLLISION" If it appeared to him that the intruder was on a non-collision course, "MISS" was to be indicated.

The instructions emphasized the point that the subject was to provide a complete record of his decision processes. His responses were to change as his decisions changed. He was reminded that he should try to respond just as he would in a real situation.

The procedure made it possible to determine the points at which the pilot became certain and/or correct about the nature of the threat.

The experimental design was factorial, and the following treatments were employed

- 7 levels of miss distance
- 3 levels of initial detection range
- 3 levels of time to closest approach
- 2 levels of field structure (clouds absent and simulated clouds present).

The initial bearing angle and quadrant in which the miss vector lay were randomized.

A training period was scheduled during the pilot runs prior to the first experimental session. The purpose of training was to insure that skillful use of the response buttons and familiarity with the simulator was achieved before the experiment proper began. Each subject was allowed to practice fixating a particular point on the dome when instructed to do so.

C. OUTLINE OF EXPERIMENTAL PROCEDURE

A prepared set of instructions was provided (Appendix B). The subject was told that he was to sit in the simulator cockpit and, when directed to do so, to fixate on a specific area of the dome. (A two-minute adaptation period was allowed.) The target was then started on its course by the operator when the subject signaled that he saw the target. He was to keep indicating "UNDECIDED" until he was able to make a judgment of "COLLISION" or "MISS". Then he was to move the switch to the appropriate position. The subject was to change his response as he changed his decision. Target shape was an aircraft silhouette.

After the shutter automatically closed, ending the run, the experimenter consulted his run sheet which provided the values of the variables which were to be manipulated from trial to trial. He set the target for its next run and informed the subject where to look when it was to be presented. There was a brief interval between trials.

A second operator was responsible for insuring that the six-channel Brush recorder was working correctly and made any adjustments and notations that were required. Records of subjects' responses, range, range rate, and sight-line rate of the target were obtained on four of the channels. A time base was provided on the time pulse channel.

Each session took one and one half hours. There were four sessions per day, two in the morning and two in the afternoon. Each pilot appeared according to a pre-arranged balanced schedule.

D. EXPERIMENT DESIGN AND SUBJECT SCHEDULE

A 7 x 3 x 3 factorial design was utilized with 10 replications of each treatment for each subject. In addition, two levels of field structure were run in 4 blocks of 5 days each. Each of the four subjects received 63 treatments per session. The sequence of trials followed a random order from one of two run sheets. These sheets were alternated for each subject.

E. RESULTS

This experiment was evaluated by analyzing the effects of the independent variables upon collision decision frequency, time remaining after final decision, and line-of-sight rate at time of final decision.

In all curves which follow, data points are connected by straight lines to aid in locating them. These lines are not to be construed as indicating the value of the variables at intermediate points.

References to range values are based upon an assumed intruder wing span of 100 feet.

1. Collision Decision Frequency

Table 3-13 shows collision decision frequency. It can be seen that collision decision frequency decreased as miss vector increased. Collision decision frequency decayed much more rapidly as miss distance increased for vertical misses compared to that for horizontal misses (figure 3-11). Decision frequency for vertical misses was not affected by structure (figure 3-12). Collision judgments were more frequent with structure for actual collisions and near horizontal misses, and were less frequent for greater horizontal misses. A possible reason that the horizontal misses were judged as collisions more frequently than vertical misses of the same magnitude is that the presence of the horizon may have served as a reference. A comparable horizontal reference was not present.

The presence of structure generally enabled the pilots to more correctly distinguish misses from collisions. Structure was of most benefit for the horizontal misses. It is possible that structure enabled the pilots to better use the fixity criterion in distinguishing collisions from misses. In certain cases the presence of structure may have served to lower the threshold for movement and because of this facilitated the designation of misses as misses. Structure was of less benefit with large misses when other criteria in addition to fixity could be employed. As a rule, structure seemed to help in the assessment of the situation.

Collision judgments for programmed collision courses were slightly higher for the 5.0-mile initial detection range than for the 2.5-mile detection range. Collision decision frequency was not any higher for detection ranges of 10.0 miles.

Collision judgments for true misses tended to decrease as detection range increased.

2. Time Remaining After Final Decision

A summary of the Analysis of Variance of Remaining Time is shown in table 3-14.

All factors, with the exception of structure, had significant effects upon time remaining after final decision. Two-factor interactions which may be of particular interest are also shown.

As can be seen in table 3-15, miss vectors ranging from 1000 feet horizontal to 250 feet vertical had about 16-seconds remaining time. (As was seen above these miss vectors were most frequently judged to be collisions.) For greater miss distances, remaining time was about 20 seconds. Clear misses were judged more quickly than courses judged as collisions. Mean remaining time was approximately one-half of the time to closest approach - for both 20 and 40 seconds - for all miss vectors most frequently judged as collisions.

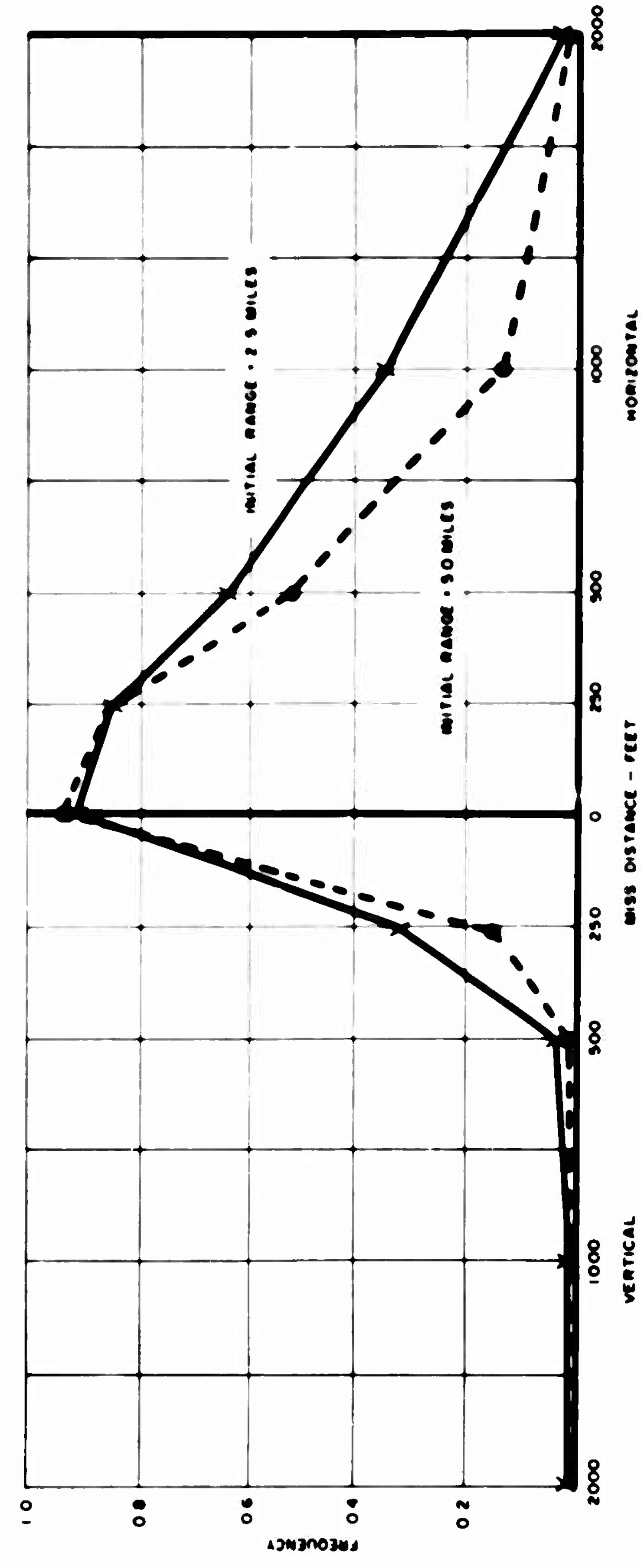


FIGURE 3-11 FREQUENCY OF COLLISION JUDGEMENTS VS MISS DISTANCE

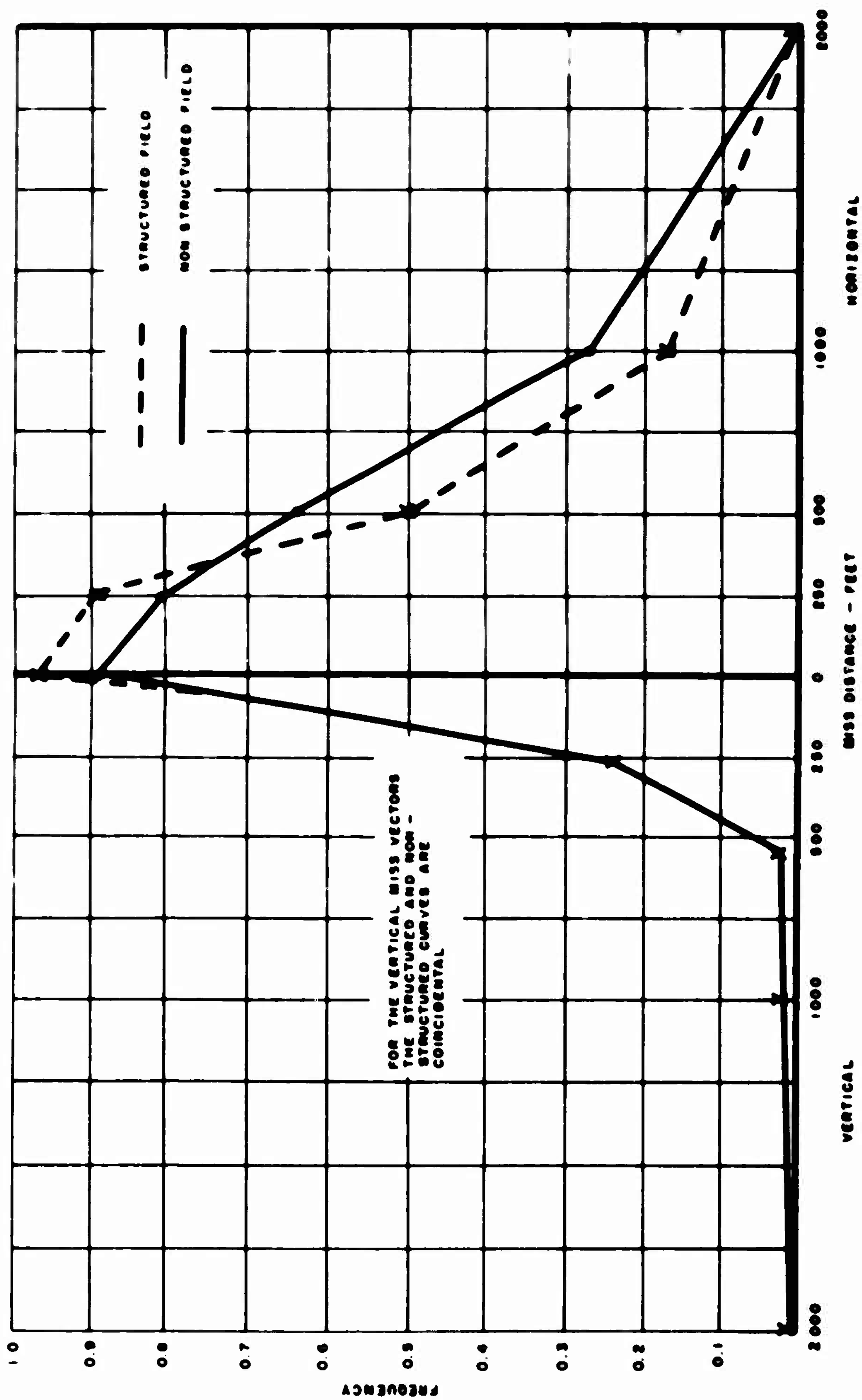


FIGURE 3-12. THE EFFECT OF FIELD STRUCTURE ON FREQUENCY OF COLLISION JUDGEMENTS

3. Line-of-Sight Rate at Final Decision

Line-of-sight rate for courses judged as collisions was about 6 minutes of arc per second regardless of structure or miss vector (table 3-16). For courses judged as misses, the line-of-sight rate was about 9 minutes of arc per second. Miss decisions for horizontal misses when no structure was present had twice this line-of-sight rate (18 minutes of arc per second.) The presence of the horizon may have provided a structured reference for misses in the vertical dimension when other structure was lacking. For all cases (except the non-structured horizontal courses judged as misses) the line-of-sight rate was between 6 and 9 minutes of arc per second. However, these figures may not be regarded as true motion-threshold values since pilots reported using criteria other than fixity in judging whether or not an intruder was on a collision course. One criterion frequently used by the subjects was the amount of separation between the intruder and the horizon. Stationary planes which were clearly above the horizon were immediately judged to be misses. The fact that the line-of-sight rate for miss decisions was about 3 minutes of arc per second higher than for collision judgments indicates that perceived movement may sometimes have been used as a cue to help decide that the intruder was on a non-collision course. Judgments of courses originally considered to be collision were most likely changed when intruder motion was perceived.

F. CONCLUSIONS

The purpose of this experiment was to determine the usefulness of the increased observation time and detection range resulting from PWI.

Judgments of the intruders' course were generally more correct at greater detection ranges.

Forty seconds available observation time resulted in twice the amount of time remaining after final decision as compared to 20 seconds available time. This fact is evidence against the existence of a decision threshold within this region, i.e. a point to which an intruder must come before the pilot is able to make a decision. If such a threshold existed, increased detection ranges and increased available time would not be used by the pilot and an increase of available time would not result.

In the context of the present experimental situation, it was shown that an increase of detection range and a consequent greater available time would result from the use of a Pilot Warning Instrument which can be of value in the evaluation of the threat posed by an intruder.

TABLE 3-13

EXPERIMENT 4

COLLISION DECISION FREQUENCY

Initial Range (miles)	Miss Vector (ft)								
	Horizontal				Coll.	Vertical			
	2000	1000	500	250		250	500	1000	2000
2.5	.0188	.3365	.6415	.8558	.9125	.3094	.0281	.0063	.0031
5.0	.0125	.1375	.5250	.8589	.9438	.1599	.0125	.0063	.0031
10.0*	-	.0256	.3750	-	.9434	-	.0250	0	-

*Note: Courses originating from 10.0 miles were not included with all miss vectors

TABLE 3-14

EXPERIMENT 4

SUMMARY OF ANALYSIS OF VARIANCE*

The Influence of Experimental Factors Upon Time Remaining After Final Decision

Source of Variation		Sum of Squares	d.f.	Mean Square	F	P
1	Subjects	143.55	3	47.85	495.00	<.01
2	Structure	0.24	1	0.24	2.38	>.05
3	Detection Range	80.52	1	80.52	835.00	<.01
4	Programmed Miss Vector	203.15	8	25.39	264.00	<.01
5	Time to Closest Approach	798.04	1	798.04	8270.00	<.01
6	Rate of Climb	0.61	1	0.61	6.35	<.01
2 X 4	Structure X Miss Vector	6.57	8	0.82	8.50	<.01
3 X 4	Range X Miss Vector	14.05	8	1.76	18.19	<.01
4 X 5	Miss Vector X Time	10.16	8	1.27	13.16	<.01
4 X 6	Miss Vector X Rate of Climb	8.42	8	1.05	10.91	<.01
	Within Treatments	498.44	5184	0.096		
	Total	1916.83	5759			

*Only those interactions of interest are included in this table

TABLE 3-15

MEAN REMAINING TIMES
AFTER FINAL DECISION (SECS)

		Miss Vector (ft)								
		Horizontal				Coll.	Vertical			
		2000	1000	500	250		250	500	1000	2000
Time to Close	20 Secs	14.8	12.6	9.9	11.0	10.5	10.5	12.8	16.5	17.6
	40 Secs	28.9	22.5	22.2	22.2	25.5	22.0	29.0	34.5	36.7
Field	Unstructured	19.5	15.3	15.0	15.5	15.3	16.5	19.0	23.5	24.9
	Structured	21.7	17.3	14.8	14.8	16.5	14.0	19.6	24.0	26.0

TABLE 3-16

LINE-OF-SIGHT RATE OF 50% FREQUENCY (MINUTES OF ARC PER SEC)

Decisions	Field	Horizontal Misses	Vertical Misses
Collision	Structured	5.4	6.6
	Non-Structured	6.0	5.4
Miss	Structured	10.20	9.00
	Non-Structured	18.0	9.00

Note: True collisions not included, since line-of-sight rate = 0

EXPERIMENT 5 - MANEUVER STUDY

The purpose of this experiment was to determine the effect of PWI on pilots' maneuvering performance.

A. DISCUSSION AND OUTLINE OF EXPERIMENT

As has been shown in Experiment 3, PWI can increase the range at which intruder aircraft can be detected. The effect of PWI on pilots' ability to evaluate the course of an intruder plane was studied in Experiment 4. Both detection and evaluation lead to a decision concerning the direction of the course to be flown. To obtain a complete analysis of the effects of PWI it was necessary to study the performance of pilots who executed avoidance maneuvers. One basic consideration in the assessment of PWI is determining whether the information provided enables the pilot to initiate an avoidance maneuver at a time significantly earlier than would have been possible without this information. Other considerations are the necessity of maneuver, the final miss distance resulting from the maneuver, and the acceleration imposed on the aircraft during the maneuver.

Whether or not detection time and/or decision time are enhanced by PWI, its use can be justified only if it leads to an earlier appropriate maneuver. This means that the pilot will change his course at an earlier time than if he did not have PWI, and that the chosen maneuver will result in a non-collision course.

The increased detection range resulting from PWI may have an undesirable effect on pilot behavior, such as unnecessary maneuvering when an intruder is mistakenly judged to be on a collision course. It is also possible that premature maneuvering may bring a pilot closer to an intruder than if he had not changed course. Therefore, it was thought necessary to study the appropriateness of each maneuver as well as the maneuver time.

The present experiment was similar in part to the Evaluation Study, Experiment 4, in which a pilot flying at a fixed altitude and heading judged whether or not an intruder plane was going to collide with his plane. The pilot had no control over his course and could do nothing to avoid the intruder. In the present study, however, the pilot was instructed to change the miss-distance relationship between his own plane and the intruder if, and only if, he decided that collision would occur. This experiment should be regarded as an attempt to obtain a qualitative indication of the effectiveness of maneuvering. Its purpose is to provide insight into aspects of the use of PWI which were not touched upon in the previous experiments.

Only a limited variety of situations were employed in this experiment. It would have been desirable to impose several additional controls in order to provide a more complete picture of the relevant factors involved in maneuvering. However, in spite of any limitations, it delves into an area which is presently devoid of data and the results provide new information.

The experimental procedure was as follows. The subject flew the F-100 simulator during all of each run. Each run was divided into two parts. The first part of the run lasted from intruder detection to, but not including, the beginning of the avoidance maneuver, if any. In this part, the course of the intruder in relation to the subject was not under control of the subject and remained constant no matter how the subject maneuvered the F-100. The subject flew the F-100 on a straight and level course at a constant airspeed, during this part of the run. The intruder's course followed any perturbations in the F-100's course so that the predetermined relative course was preserved. If the subject decided to make an avoidance maneuver he started the second part of the experimental run by pressing the release button, located on the control stick. In this case, the intruder continued on its programmed unaccelerated flight path, and the effect of the F-100 maneuvers were included in determining the relative position of the projected intruder (aircraft silhouette)

The subject was told the location of the intruder plane at the start of each run. The stationary intruder was projected on the dome. The subject pressed a signal button when he located the intruder which started the intruder on its preset course.

The subject was instructed to act as much as possible as if he were in a real flying situation. If he thought that an avoidance maneuver was necessary, he was to press the release button and execute a maneuver. If no maneuver was made, the intruder continued on its course to minimum range and then the shutter closed.

The measures of pilot performance were studied as a function of target size at detection, available observation time, and level of collision threat. Maneuver time was defined as the programmed time to close minus the time between initiation of the run and initiation of the maneuver. The instructions read to the subjects are shown in Appendix C.

B. DATA COLLECTION

To obtain a measure of maneuver time a timer was stopped whenever the release button was pressed. An operator recorded this time. The following information was obtained on a Brush recorder:

F-100 performance:
- Acceleration magnitude
- Heading
- Altitude
- Airspeed
- Slant range (distance between F-100 and intruder)

An event mark was recorded for shutter opening, start of intruder run, pressing of release button, and shutter closing.

A factorial experimental design with the following treatments was employed

7 levels of miss distance

3 levels of initial target size

2 levels of field structure

2 levels of observation time

Initial bearing angle and the quadrant in which the miss vector lay were randomized.

C. SUBJECT TRAINING

Twelve pilot subjects were trained to fly the simulator on a straight and level course without continuous reference to the cockpit instruments. This training was undertaken several weeks before the experiment.

A final training period was scheduled prior to the first experimental session. Subjects were instructed and were familiarized with the experimental apparatus. Trial runs under all conditions were carried out and subject performance was analyzed to insure that the instructions were understood and followed.

D. EXPERIMENT DESIGN

There were 42 runs per session. The time provided to complete one session was one hour. Six sessions per day, three in the morning, three in the afternoon, were scheduled. Two run sheets were provided with different trial randomization. They were alternated for each subject. The 12 subjects were run in two blocks of six subjects per block. Each subject had one session per day for six days.

EXPERIMENTAL DESIGN

TREATMENT	LEVELS	VALUES	
		Vertical	Horizontal
Miss distance (ft.)	7	0, 250, 375, 500	0, 1000, 2000, 3000
Initial range (miles)	3	2.5, 5.0, 10.0	
Time to closest approach (secs)	2	20, 40	
Field	2	Structured and unstructured	

E. RESULTS

An analysis of the effects of the experimental factors upon the dependent variables - maneuver frequency - time remaining after maneuver, slant range at maneuver, and final miss distance is given here.

1. Maneuver Frequency

Figure 3-13 shows maneuver frequency for all courses with closing speeds of 450 knots; figure 3-14 gives similar data for 900 knots. As can be seen, 40 seconds of available observation time results in higher maneuver frequencies than 20 seconds for all miss vectors. Figure 3-15 shows maneuver frequency for three closing speeds with 20 seconds available observation time. Frequencies for the 900 and 1800 knot speeds are similar, with frequencies for 450 knots somewhat higher. Maneuver frequency generally decreases as miss vector increases. It is not understood why the 500-foot vertical miss vector is an exception to this trend. Note that, for a given initial miss vector, the maneuver frequency in Experiment 5 is significantly higher than the collision decision frequency in Experiment 4. Moreover, earlier detection tended to increase unnecessary maneuvering in Experiment 5 as opposed to decreasing incorrect collision decisions in Experiment 4. The obvious differences in frequencies for similar miss vectors for decision frequency in Experiment 4 and maneuver frequency in Experiment 5 may be due to the differences in the instructions and the tasks analyzed. Experiment 4 frequencies are for final decision whether "collision" or "miss". Decisions could be changed by the subjects as often as desired. In Experiment 5, once a maneuver was made the decision to maneuver could not be reversed.

Table 3-17 shows maneuver frequencies for all miss vectors for structured and unstructured fields. The slight differences between the fields are inconsistent and may be considered as being due to chance.

FIGURE 3.13 MANEUVER FREQUENCY 480 KNOT RELATIVE VELOCITY

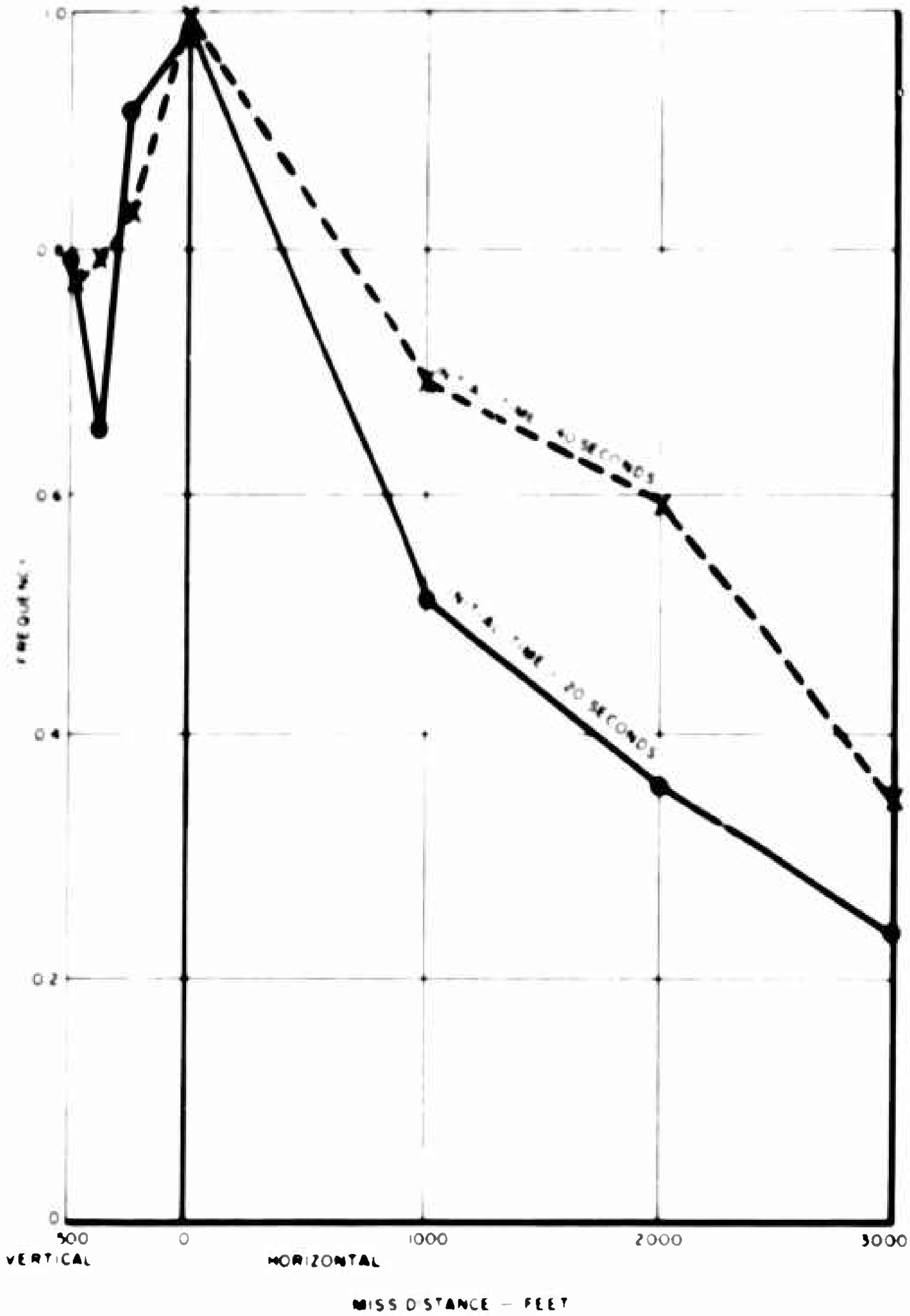


FIGURE 3.14 MANEUVER FREQUENCY 900 KNOT RELATIVE VELOCITY

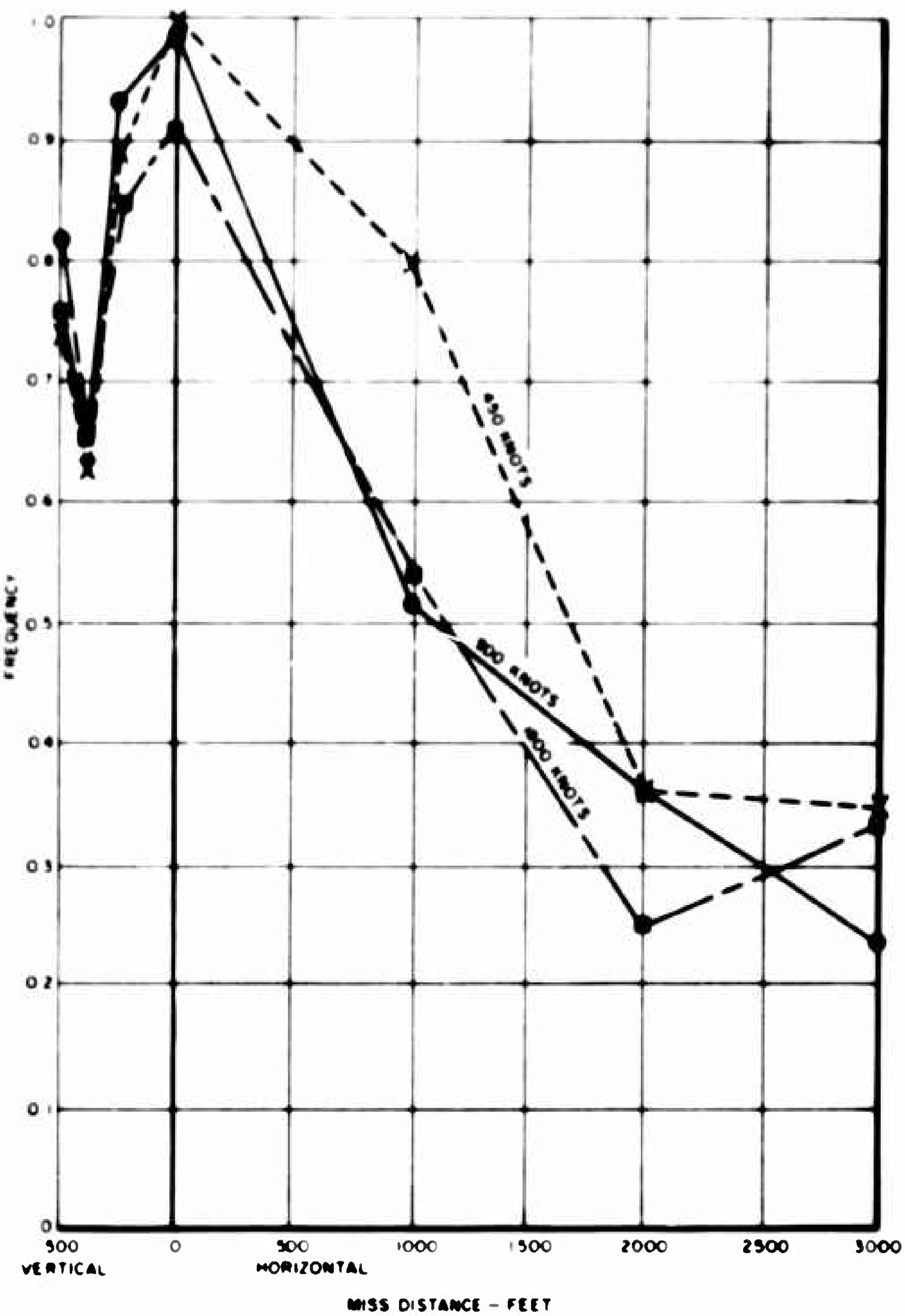


FIGURE 3-15 MANEUVER FREQUENCY – INITIAL TIME 20 SECONDS

2. Time Remaining after Maneuver

Remaining time was independent of both miss vector and structure (table 3-18). Remaining time averaged over miss vector is shown in table 3-19. For the same initial range, remaining time after maneuver for 40 seconds available time was approximately twice that for 20 seconds available time. As velocity increased remaining time decreased. For a given velocity, doubling available time increased remaining time by about 60 percent.

3. Slant Range at Maneuver

Correspondingly, slant range at maneuver increased about 60 percent when available time was doubled for a given velocity (table 3-20). For a given range, greater available time resulted in a small increase of range at maneuver. Structure had no influence on range at maneuver (table 3-21). Mean angular size at maneuver is given in table 3-22. For purposes of generalizing to all types of aircraft, the angular size data are more useful. The range and velocity values shown in tables 3-19, 3-20 and 3-2. are arbitrary, since they are based upon an assumed intruder wing span of 100 feet. However, corresponding values may be easily computed for an aircraft of any assumed size.

4. Final Miss Distance

Final miss distance was generally increased as a result of the maneuver undertaken (table 3-23). However, for speeds of 1800 knots, maneuvering never significantly increased miss distance. In fact, the maneuvers were often harmful, since they resulted in a reduction of miss distance. Miss distance increased as speed decreased. For a given speed, increased detection time generally increased miss distance. The evasive maneuvers undertaken had up to 3 G's acceleration. Structure had no marked effect on final miss distance. Table 3-24 shows the amount and the direction of change of miss distance from the miss distance which would have resulted if nomaneuver were made. Figures 3-16 through 3-19 are cumulative frequency curves showing the relationship between final miss distance and the programmed closing speeds for collision encounters. Figures 3-17 and 3-18 allow a comparison of the results of the two available observation times employed in the experiment. For speeds of both 450 and 900 knots, greater miss distances resulted with greater available time.

Figure 3-20 is a corresponding curve for an initial miss vector of 1000 feet, averaged over initial time and range (the values of the latter variable had no consistent effect on the results). This curve shows that, although the mean miss distance is increased as a result of the maneuvers, the data spread is great enough that, in a significant number of cases, the maneuver resulted in a decrease in miss vector.

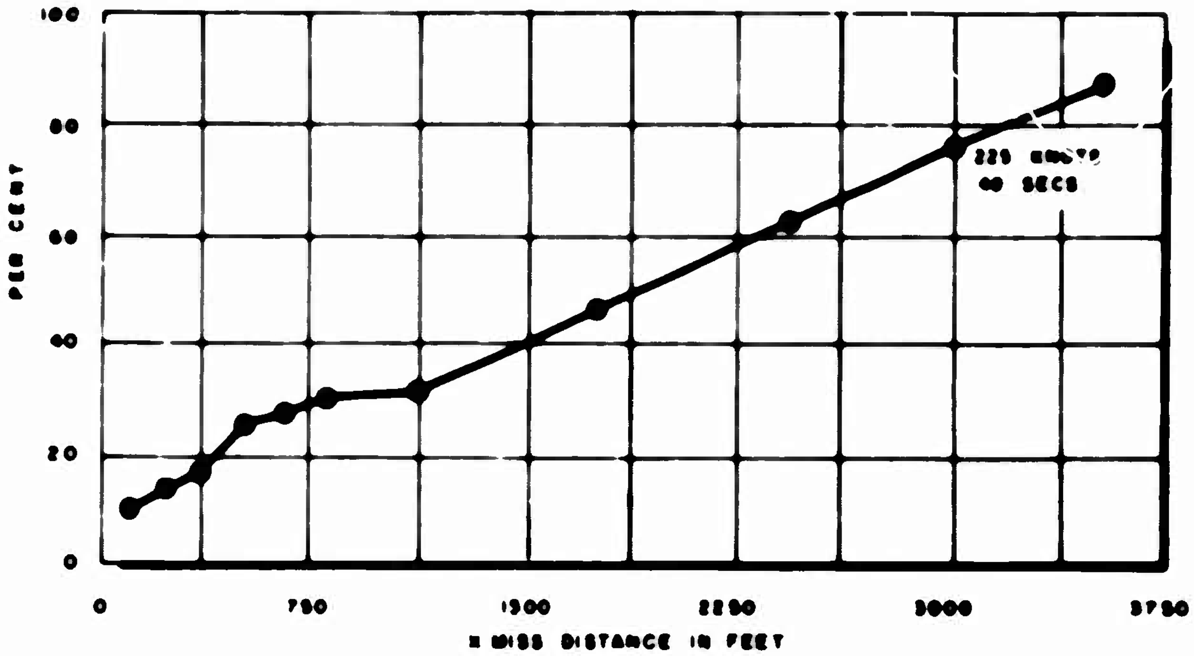


FIGURE 3-16. FREQUENCY OF FINAL MISS DISTANCE LESS THAN X FEET FOR COLLISION COURSES - 225-KNOT RELATIVE VELOCITY

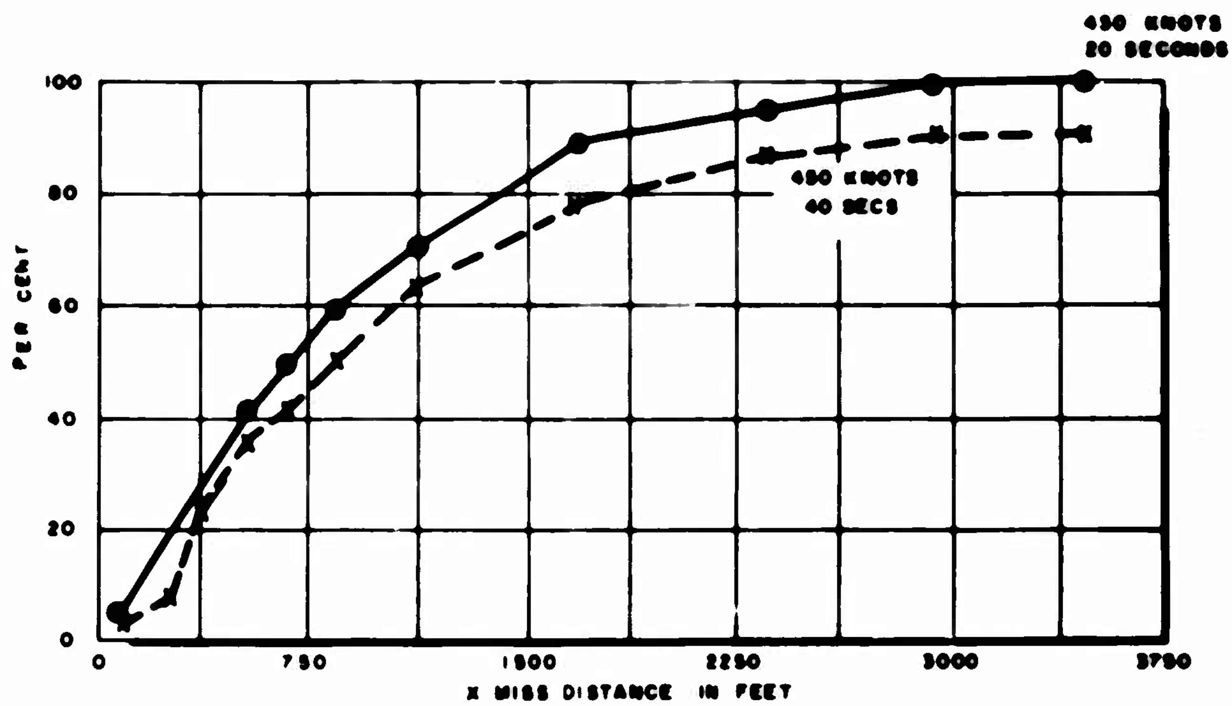


FIGURE 3-17. FREQUENCY OF FINAL MISS DISTANCE LESS THAN X FEET FOR COLLISION COURSES - 450-KNOT RELATIVE VELOCITY

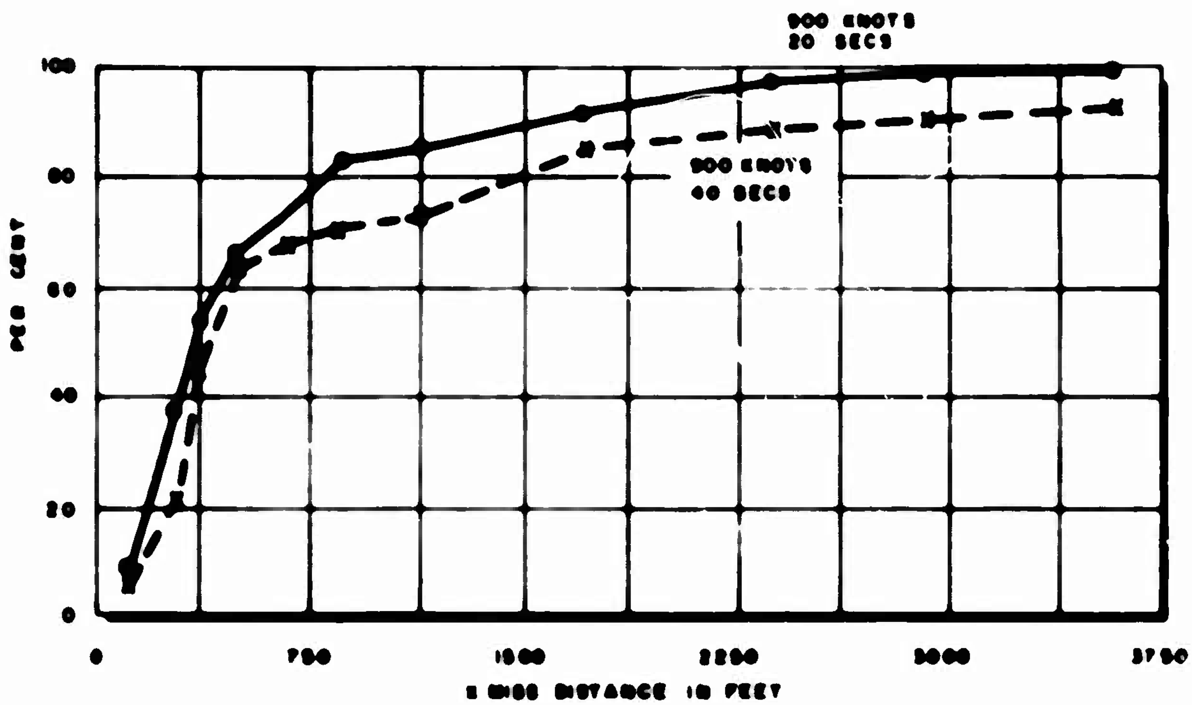


FIGURE 3-18. FREQUENCY OF FINAL MISS DISTANCE LESS THAN X FEET FOR COLLISION COURSES - 900-KNOT RELATIVE VELOCITY

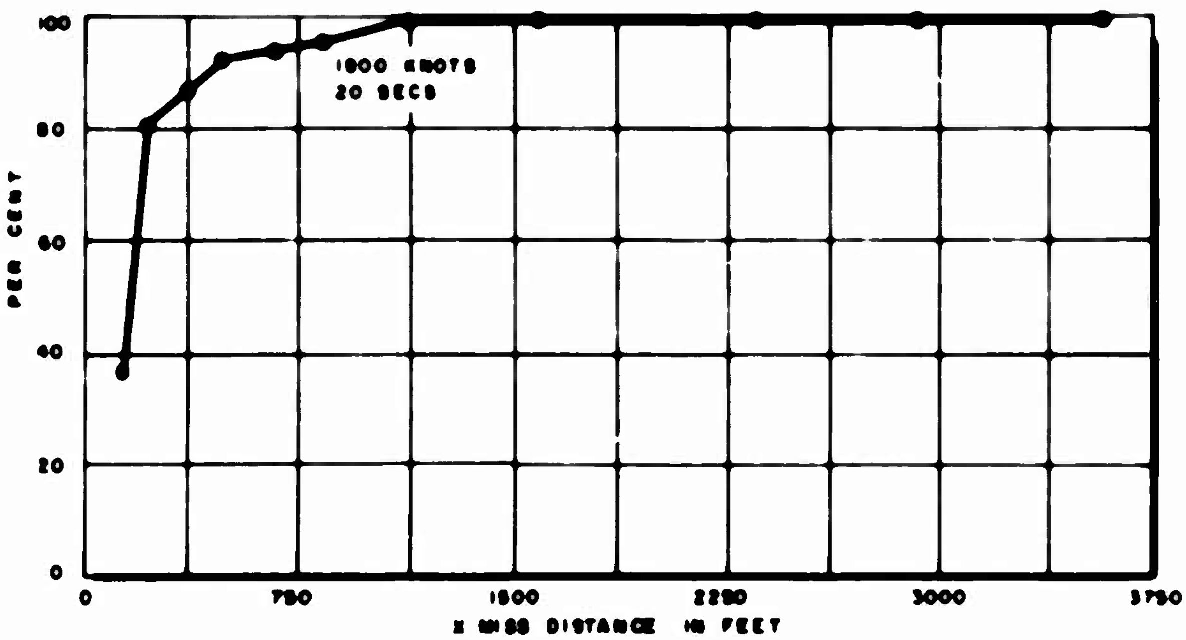


FIGURE 3-19. FREQUENCY OF FINAL MISS DISTANCE LESS THAN X FEET FOR COLLISION COURSES - 1800-KNOT RELATIVE VELOCITY

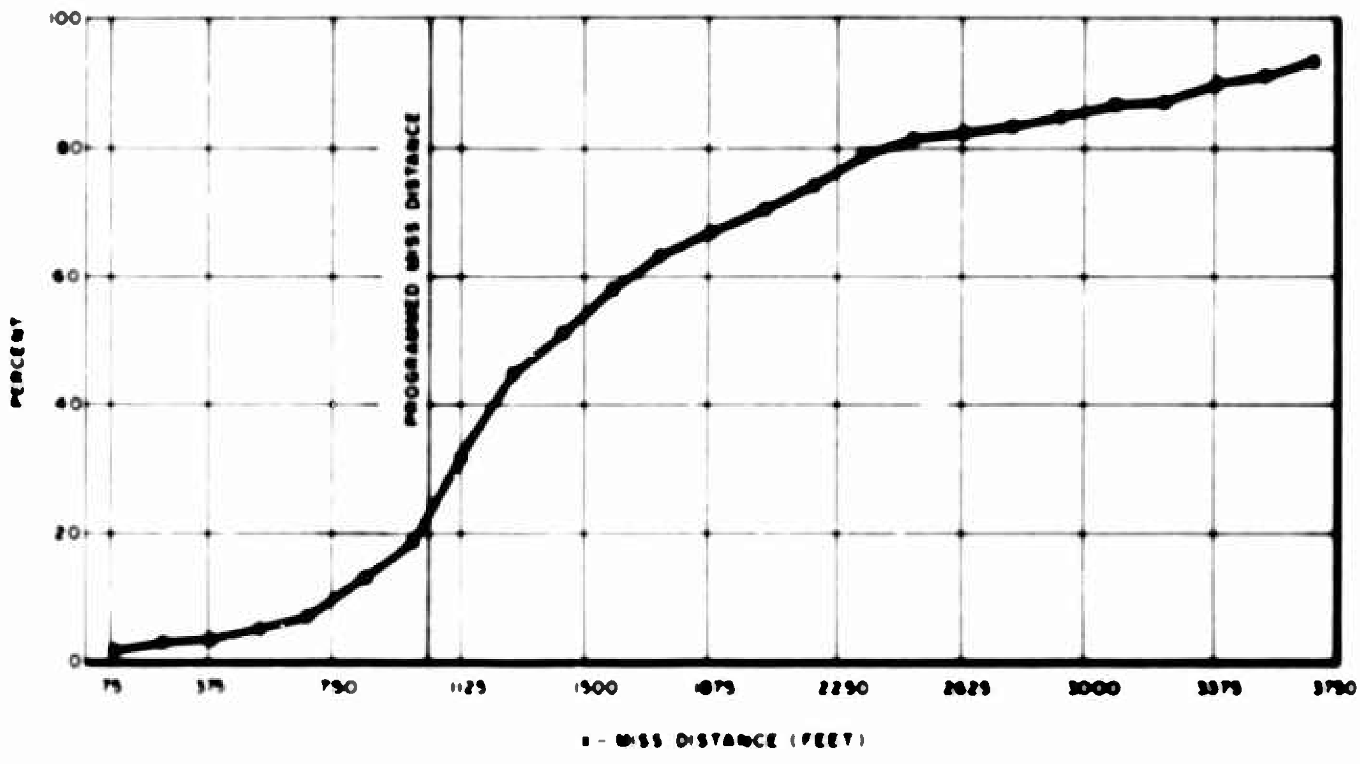


FIGURE 3-20 FREQUENCY OF FINAL MISS DISTANCE LESS THAN X FEET FOR ALL 1000 FOOT HORIZONTAL MISSES

An interesting finding in this experiment is the relationship obtained between final miss distance and remaining time. For small miss vectors (which were also vertical misses in this experiment), final miss distance was correlated with remaining time, i.e., how early the maneuver occurred (figure 3-21). The earlier the maneuver the greater was the final miss distance. For large miss vectors, final miss distance was independent of remaining time and correlated with initial miss vector. For the large miss vectors (not shown in figure 3-21) it is possible that gentle maneuvers were performed, prior to a decision, to help evaluate the threat, and were terminated before any significant change in miss vector developed.

G. CONCLUSIONS

1. When an intruder who represented a collision threat was detected, a maneuver resulted almost 100 percent of the time, regardless of the amount of lead time provided. For non-collision cases, earlier warnings resulted in higher maneuver frequencies.

2. Earlier detection resulted in an earlier maneuver.

3. Up to 900 knots closing rates, evasive maneuvers up to about 3 G's were effective when detection time was at least 20 seconds. For a given closing rate, increasing detection time or range increased final separation.

4. The following points compare the findings of Experiment 5 to those of Experiment 4:

- Earlier detection resulted in an earlier maneuver as well as an earlier decision regarding the threat.
- Structure had no appreciable effect in Experiment 5, whereas its influence was apparent in Experiment 4.
- In Experiment 5, maneuver frequency for a given miss distance was much higher than collision decision frequency in Experiment 4. The maneuver frequency curve does not fall below 50 percent until miss distance reaches 3000 feet in the horizontal dimension. This effect may be due to more closely simulating the pressures of a real-world environment.
- Similarly, earlier detection in Experiment 5 resulted in a higher false alarm rate, as contrasted to the opposite results of Experiment 4. This discrepancy in results vitiates any conclusions regarding the effect of early detection on unnecessary maneuvering.

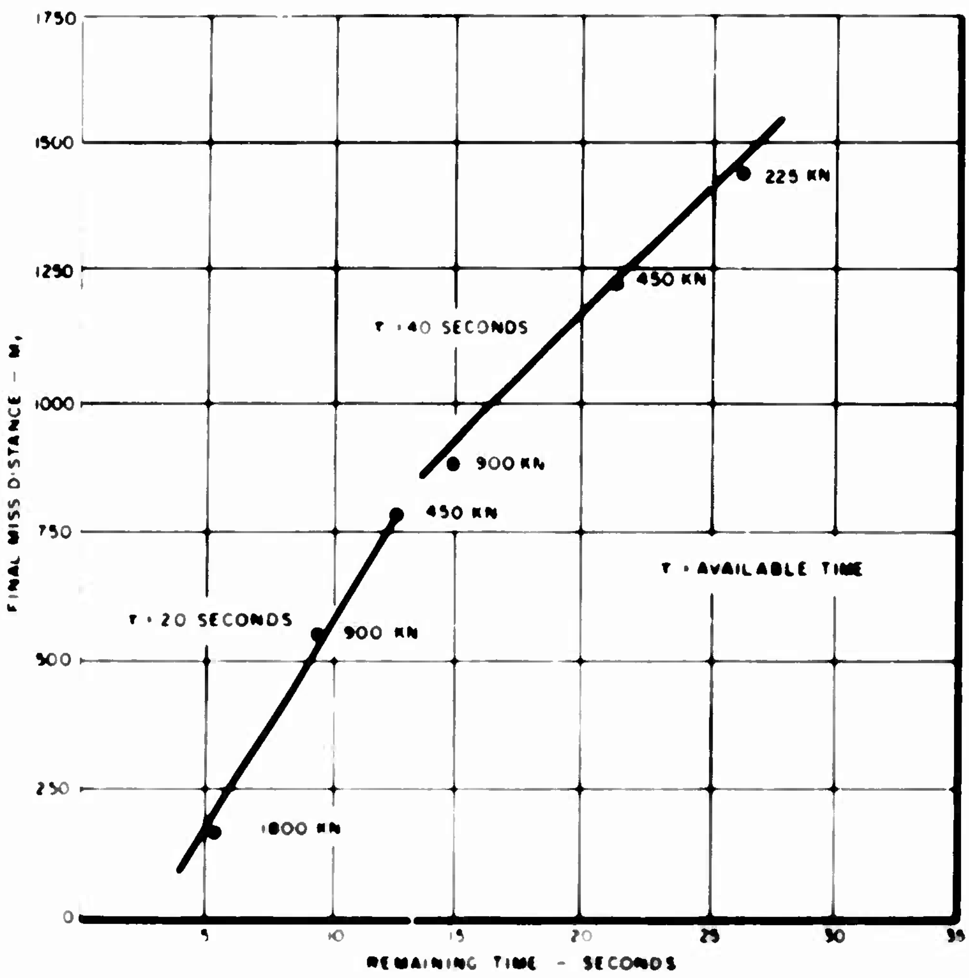


FIGURE 3.21 THE RELATIONSHIP BETWEEN FINAL MISS DISTANCE AND REMAINING TIME FOR INITIAL MISS VECTORS OF 800 FEET OR LESS

TABLE 3-17

MEAN MANEUVER FREQUENCY

	Miss Vector (ft.)							
	Horizontal				Vertical			
	3000	2000	1000	Coll	250	375	500	$\bar{X}$
Maneuver Frequency								
Structured	.2963	.4074	.6759	.9815	.8519	.7454	.7870	.6729
Unstructured	.3102	.4444	.6667	.9860	.8796	.6852	.8065	.6827

TABLE 3-18

MEAN REMAINING TIME
AFTER MANEUVER (SECS)

	Miss Vector (ft.)						
	Horizontal				Vertical		
	3000	2000	1000	Coll	250	375	500
Remaining Time $\bar{X}$	15.94	16.16	15.22	15.02	14.27	16.03	14.10
Structured	15.86	16.72	17.67	15.06	14.27	16.07	14.63
Unstructured	16.02	15.64	14.77	14.98	14.26	15.99	13.56

TABLE 3-19

MEAN TIME REMAINING AFTER MANEUVER

		Initial Detection Range (Miles)		
		2.5	5.0	10.0
Available Time	20 Secs	12.59	9.37	5.86
	40 Secs	23.05	20.69	14.70

225 450 900 1800

Speed (Knots)

TABLE 3-20

MEAN SLANT RANGE AT MANEUVER

		Range (miles)		
		2.5	5.0	10.0
Available Time	20 Secs	1.57	2.33	[illegible].95
	40 Secs	1.62	2.56	[illegible].67

225 450 900 1800

Speed (Knots)

TABLE 3-21

MEAN SLANT RANGE (MILES) AT MANEUVER

		Miss Vector (ft)						
		Horizontal			Coll	Vertical		
		3000	2000	1000		250	375	500
Field	Structured	2.77	2.75	2.53	2.38	2.37	2.47	2.50
	Non-Structured	2.75	2.78	2.44	2.34	2.42	2.56	2.31
Available Time	20 Secs	2.34	2.37	2.49	2.12	2.11	2.38	2.28
	40 Secs	3.20	3.00	2.48	2.59	2.69	2.61	2.52

TABLE 3-22

MEAN ANGULAR SIZE (MINUTES) AT MANEUVER

		Miss Vector (ft)						
		Horizontal			Coll	Vertical		
		3000	2000	1000		250	375	500
Field	Structured	28.96	30.90	32.80	30.14	31.88	29.04	28.96
	Non-Structured	25.94	28.34	30.52	29.72	33.58	32.66	38.00
Available Time	20 Secs	32.52	35.44	31.40	32.06	35.12	33.40	35.00
	40 Secs	22.22	25.96	31.90	27.90	30.20	28.60	31.90

TABLE 3-23

MEAN FINAL MISS DISTANCE (FEET)

		Miss Vector (feet)							Speed (Knots)	$\bar{X}$
		Horizontal			Coll	Vertical				
		3000	2000	1000		250	375	500		
Range	Time									
2.5	20	4152.00	2380.77	2207.14	830.14	947.31	1190.22	1019.44	450	1818
2.5	40	3207.69	2119.44	1946.43	1968.49	1490.48	1805.00	1591.84	225	2018
5.0	20	3679.41	2561.54	977.03	531.25	662.69	675.00	799.14	900	1412
5.0	40	2766.67	2714.15	2178.46	1212.33	1540.32	1126.32	1665.00	450	
10.0	20	3031.25	1950.28	1319.23	141.04	191.13	304.79	241.53	1800	1025
10.0	40	2916.00	3005.81	1389.00	867.81	1160.66	1178.95	1965.32	900	2018

TABLE 3-24

MEAN CHANGE IN MISS DISTANCE (FEET)

		Miss Vector							Speed (Knots)
		Horizontal			Coll	Vertical			
		3000	2000	1000		250	375	500	
Range	Time								
2.5	20	1152.00	380.77	1207.14	830.14	697.31	815.22	519.44	450
2.5	40	207.69	119.44	946.43	1968.49	1240.48	1430.00	1091.84	225
5.0	20	679.41	561.54	-22.97	531.25	412.69	300.00	299.14	900
5.0	40	-233.33	714.15	1178.46	1212.33	1290.32	751.32	1165.00	450
10.0	20	31.25	-49.72	319.23	141.04	-58.87	9.78	-258.47	1800
10.0	40	-84.00	1005.81	389.00	867.81	910.66	803.95	465.32	900

EXPERIMENT 6

This experiment was designed to provide a limited test of the hypothesis that targets which have equal intrinsic probabilities will have equal probabilities of detection in search, for a constant level of PWI and average work load. If verified, this relationship would have enabled generalization, to the real world, of data obtained in simulated flight.

A. DISCUSSION

The intrinsic probability of detection (P_i) of a target is defined to be the probability that the target will be seen when the region of the appearance of the target is fixated and the target is exposed for one second. In Experiments 1 and 1A it was shown that P_i is a function of target size, shape, and contrast ratio. In the real world P_i is a function of these and other factors.

The probability of detection in search (P_s) is the probability that the subject detects the target within some fixed time when the region in which the target will appear is randomly varied.

Information concerning the presence and/or location of the target may be provided to the subject. It is assumed that P_s is a function of

- Search time
- Target information
- Work load of subject
- P_i of the target

B. METHOD

1. Subjects and training

All subjects were checked for normal vision. They were then tested for a period of two weeks in order to establish detection thresholds under fixation for circular targets of 3, 6 and 12 minutes of arc size. These detection frequency values were then used to determine target brightness for the experiment proper.

A determination of detection when there is foveal fixation was repeated after completion of the experiment in order to determine the stability of the obtained intrinsic probabilities. Thus, this study consisted of three phases

- Pre-experimental determination of intrinsic probabilities of detection
- Experiment proper - the determination of probabilities of detection under search
- Post experimental determination of intrinsic probabilities of detection.

Prior to the commencement of the experimental search conditions the subjects were trained to locate an area of the dome when they were given a specific azimuth reference. Easily detectable targets were used at first, and when a subject's proficiency was apparent, targets progressively approaching the values of the experimental stimuli were presented. After several training sessions all subjects were able to localize the area of the dome where they were told to look, with accuracy and consistency.

2. Procedure

Subjects were seated in the cockpit of the F-100A simulator. Their task was to indicate when they found circular targets that were projected at various locations on the dome surrounding the simulator.

Subjects were told the exact azimuth location of targets (which were presented within ± 45° azimuth) and were allowed ten seconds to find them. The targets varied from 2° to 6° in elevation, but no elevation information was given to the subject. A warning tone signaled the appearance of the target and a second tone indicated that it was no longer being presented. The subjects were instructed to press a switch whenever they detected a target. Experimenters kept a record of the subject's responses. A record also was taken of the time interval between target presentation and detection.

The experimenter followed a run sheet which contained a randomized order of presentation of targets at 57 different points on the dome.

There were ten experimental sessions for each subject. Each session consisted of 60 trials. The nine stimuli were randomly presented six times per session. There were also six sham trials on which the subject was given azimuth information and the warning tone was sounded, but no target was presented. These sham trials served to indicate the extent to which the subject guessed or hallucinated. Subjects were told that sham trials were being employed.

The average background brightness of the dome was 3.1 foot lamberts. Daily photometric readings were taken of the dome brightness at ±35° azimuth and

6^{o} elevation. This point served as a reference and was maintained at 3.1 foot lamberts throughout the experiment. Complete dome maps were taken at the start and completion of the experiment.

The stimuli employed were circular targets 3, 6, and 12 minutes of arc in size. The target rheostat was set to provide a target brightness of 0.14 foot lambert (pre-experimental period) or of 0.20 foot lambert (experimental and post-experimental periods) when projected through a 0.8 Wratten neutral density filter. This reference was checked daily. Specific stimulus brightness was controlled by utilizing Wratten neutral filters.

The intrinsic probabilities were established prior to the experiment proper. They were also rechecked after the experiment was completed. The procedure to determine the intrinsic probabilities required the subjects to fixate a region of the dome straight ahead and at eye level. This area was delineated by four points, which served to fix the subject's gaze to within $\pm 3/4^{o}$ of where the target would appear. This area was chosen to insure foveal fixation. The subjects were instructed to indicate when they saw a circular target.

A signal preceded target presentation. The detection thresholds for the subjects were established for the three target sizes. These sizes (3, 6 and 12 minutes of arc) were selected in order to bracket the Ricco region. It was felt that an adequate test of the hypothesis should include targets of sizes for which Ricco's law holds and for which it does not. The reference target brightness was 0.14 foot lambert when projected through a 0.8 Wratten neutral density filter. The obtained detection frequencies were used to determine the brightness values at the 50-percent detection point for each of the three target sizes. In order to produce three levels of intrinsic probability, the 50-percent point brightness values were multiplied by three constant factors. Thus, in order to produce relatively high intrinsic probabilities for each size target the threshold brightness was increased by approximately 0.58 log foot lamberts. To obtain a medium level of intrinsic probability threshold brightness was increased by about 0.24 log foot lamberts. The lowest level of intrinsic probability was obtained by increasing threshold brightness by 0.10 log foot lamberts. Since brightness could not be continuously varied, and only a limited number of Wratten filter combinations were possible because of apparatus limitations, the brightness increases could only be approximated. The 3-minute of arc target was 0.06 foot lambert brighter than the other targets at each intrinsic probability level. This did not result in consistently higher detection probabilities in the search tests. However, as will be seen, one obtained difference might possibly be attributed to this.

Several attempts had been previously made to empirically establish the various levels of intrinsic detection probability for the different size targets, but it was not possible to obtain stable detection probabilities. The procedure finally used for the establishment of equivalent intrinsic probabilities was predicated upon the assumption that common slopes would be obtained for the detection curves of the different size targets. This assumption was supported by the data.

The filters used in conjunction with each size target for the experiment proper are shown in table 3-25. Relative intrinsic probability levels are also shown.

The basic target brightness reference was increased to 0.20 foot lamberts when projected through the 0.8 filter in order to obtain a desirable range of probabilities of detection under search. On the basis of Experiment 3 data for the "azimuth only" condition, a basic target brightness of 0.14 foot lambert through the 0.8 filter would have resulted in search probabilities which would have been too low.

The data obtained for the pre-experimental intrinsic test have been fitted with cumulative Poisson curves (Hecht, Schlaer & Pirenne, 1941), figure 3-22. Data points obtained in a post-experimental intrinsic test have also been included, so that the results of the two tests may be compared. With the brighter targets used during the post-experimental test, a corresponding shift of the points occurred.

It is obvious that the cumulative Poisson curves do not fit the data points below 0.2 probability of detection. The greatest weight in the fitting of the curves has been given to the points considered to have the highest degree of stability, i.e., those falling between the 0.2 and 0.8 probability-of-detection levels. A possible reason for the break at the low end of the curve might be that subjects change their criteria of detection when confronted with targets that are very difficult to see. Analysis of detection curves for individual subjects reveals similar breaks for most subjects at about the 0.2 level. The veracity checks showed that the subjects were not guessing.

C. SEARCH TEST

The probabilities of detection under the search condition for the nine stimuli used are shown in table 3-26.

A comparison of counts was made at each level of intrinsic probability for the obtained search probabilities (Bennett and Franklin 1954, p 611). The search probabilities were significantly different at each level. However, no differences were found between the 3 minute-of-arc and 6 minute-of-arc targets at the high and medium intrinsic-probability levels. The search probabilities at the low intrinsic-probability level for the 3 minute and 6 minute targets, while being significantly different, differ by only 0.074 as compared to the much larger differences for the 12 minute target. It is not clear whether this difference is due to the fact that the 3 minute target was made brighter by a slightly greater factor than the 6 minute target. Nevertheless, this slightly greater proportionate brightness of the 3 minute targets did not result in significantly greater detection probabilities at the high and medium intrinsic-probability levels.

The most striking finding is that the probabilities of detection at all levels for the 12 minute target suffer less decrement under search than do those for the 3 minute and 6 minute targets.

The data may be interpreted in another way by comparing the search detection curves for the three target sizes (figure 3-23). Using the 3 minute curve as a reference, so that the distances separating the search detection curves may be compared to the distances separating the intrinsic detection curves, it is clear that the distances between the curves are greater under search. The distance between the 3 minute and 6 minute intrinsic-detection curves is 0.54 log unit and between the 3 minute and 12 minute curves 0.73 (0.54 + 0.19) log unit. The separation between the 3 minute and 6 minute search curves is 0.61 log unit and for the 3 minute and 12 minute curves 0.95 (0.61 + 0.34) log unit. The distance between the 3 minute and 12 minute curves increased by a large amount under search. The distance between the curves for the 3 minute and 6 minute targets increased by only a slight amount. This shows that the 3 minute and 6 minute targets were effected similarly under the search condition, whereas the 12 minute target was not so affected. As was previously mentioned, less degradation occurred.

D. CONCLUSIONS

The hypothesis that targets having equal intrinsic detection probabilities also have equal search detection probabilities has not been unqualifiedly supported. The results indicate that for targets of 3 and 6 minutes as compared to those 12 minutes arc in size there are differential decrements in detection probabilities due to search. This interaction between search and target size precludes the generality of the equivalence hypothesis. The hypothesis did hold at two of three intrinsic detection probability levels for the 3 and 6 minute-of-arc targets. The findings may be due to the fact that effective luminance integration occurs over a larger area in the parafovea than in the fovea, i.e., a 12 minute of arc target will obey Piper's law in the fovea, while it still obeys Ricco's law in the parafovea. (Regions in which detection is dependent on the product of retinal illuminance and image area obey Ricco's law. When detection is dependent on the product of retinal illuminance and the square root of the image area, Pipers law is being obeyed.)

These findings are evidence against the feasibility of using "intrinsic" probability as a basis of generalizing from simulators to the real world in precise mathematical terms. If the intrinsic probability of a particular flight situation could be determined, the relationship between it and probability of detection in real world search might not be the same as that between simulated intrinsic and search probabilities of detection. It is likely that stimuli differing in shape, color, and texture, as well as size, will interact differentially with the search conditions, although they might have the same intrinsic probabilities. This would result in a multiplicity of relationships between intrinsic and search probabilities of detection, each being unique for a specific stimulus configuration. Perhaps a more complex index of stimulus quality will yield orderly predictable relationships between detection probabilities under fixation and search.

The fact that the equivalence hypothesis did not obtain empirical support does in no way vitiate the previous experiments of this program. The experiments designed were not dependent upon the validity of the equivalence hypothesis. Wherever "intrinsic probability" was an independent variable, it was operationally defined in terms of size, contrast ratio, or brightness. The obtained functional relationships between contrast ratio and search probability apply for the target size used in Experiment 3

TABLE 3-25

WRATTEN FILTER AND TARGET SIZE COMBINATIONS

Target Size (Minutes of Arc)	Relative Level of Intrinsic Probability		
	High	Medium	Low
3	0	0.2	0.3
6	0.6	0.8	0.9
12	0.8	0.2 + 0.8	0.3 + 0.8

TABLE 3-26

SEARCH PROBABILITIES

Target Size (Minutes of Arc)	Relative Level of Intrinsic Probability		
	High	Medium	Low
3	.798	.467	.174
6	.772	.477	.100
12	.965	.728	.442

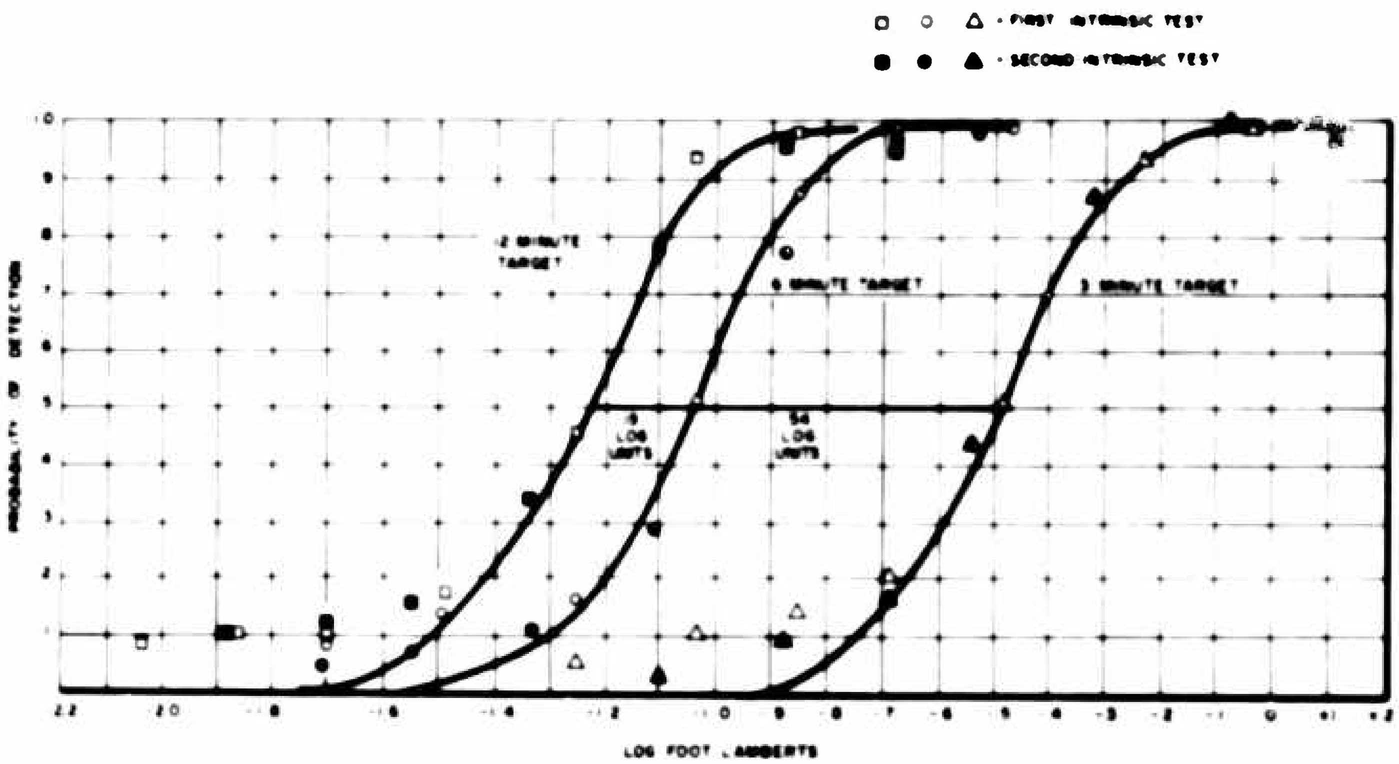


FIGURE 3-22 INTRINSIC PROBABILITIES OF DETECTION

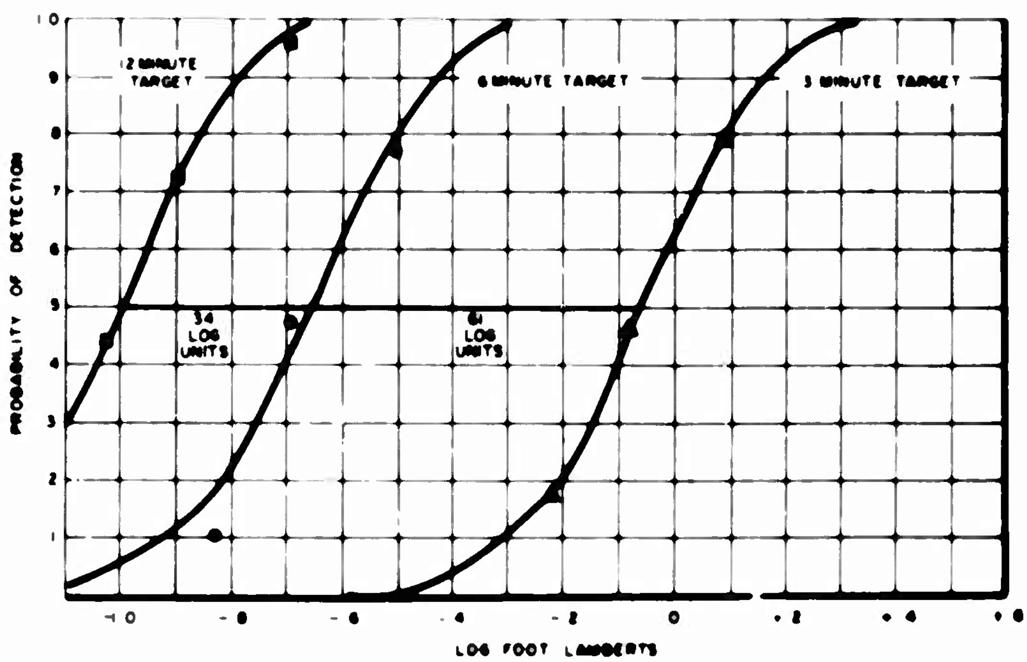


FIGURE 3-23 SEARCH PROBABILITIES OF DETECTION

SECTION IV

SUMMARY OF THE EXPERIMENTS

An experimental research program was conducted to determine the effectiveness of information provided by Pilot Warning Instruments (PWI) for reducing the incidence of mid-air collisions. The function of PWI is to aid a pilot in the visual detection of intruder aircraft. The information it provides is intended to enable the pilot to detect aircraft earlier than normally, and thus decrease the probability of collision threat remaining undetected until the danger becomes high. It was felt that if PWI facilitated detection, earlier evaluation of intruder threat and/or earlier appropriate maneuvering could result. On this basis, the effect of PWI on pilot performance relating to detection, threat evaluation, and maneuvering for collision avoidance was studied. The experimental work in the program was accomplished on an F-151 fixed aerial gunnery trainer used in conjunction with an F-100A flight simulator. Hence, the studies conducted dealt with pilot behavior in a high performance aircraft. Also, intruder detection was for liminal visual targets. Collision avoidance for supraliminal targets first detected at close range and having small closing rates was not treated in this investigation.

To evaluate the effect of PWI on the detection of intruder aircraft under simulated search conditions, it was first necessary to determine how frequently targets would be detected when search was not required, i.e., when the region in which the target appeared was constantly fixated with central vision (Experiments 1, 1A, and part of 6). This foveal non-search or "intrinsic" detection probability for a small particular target, presented at a given daylight brightness level and contrast, is theoretically the maximum probability with which it can be detected. For a target of specific angular size and shape, it was found that detection of the target never occurred below a certain target/background contrast ratio; above a certain higher contrast ratio, detection always occurred. Between these values, frequency of detection varied systematically. For detection frequencies above 20 percent, the data could be well fitted by a curve having the shape of the cumulative normal probability curve, i.e., an ogive curve. With change in target size, the slope of the central region of the ogive remained constant but was laterally displaced so that 50-percent detection (which defines threshold response) occurred at different contrast ratios. The larger the target, the lower was the contrast ratio required for its detection.

Having established the maximum frequency of detection possible for a foveally fixated target, the extent to which different levels of information to be provided by PWI helped approach this maximum, under search conditions, was studied (Experiment 3). Five levels of information concerning intruder location were used, namely:

1. azimuth (bearing angle) and elevation

2. azimuth only

3. a simple warning indicating that an intruder was present but providing no location information

4. no warning

5. a passive observer condition in which no other work was required of the observer.

Pilot work loading was present during the first four conditions. Comparing condition 4 with condition 5 serves to indicate the degree to which simulated work load affects the pilot's ability to detect aircraft.

It was found that the greater the amount of information provided by PWI, the closer was the theoretical maximum detection frequency approached. For example, a target which was detected about 95 percent of the time when presented near the visual fixation point was detected about 75 percent of the time when elevation and azimuth information were given, 50 percent of the time when azimuth information only was given, 3-1/2 percent of the time when warning information only was given, 10 percent of the time with a passive observer as subject, and only 2 percent of the time when the subject was a pilot and received no warning information (see table 3-10). Under the passive observer condition, detection of intruders occurred with greater frequency than when a simple warning was presented to the pilot while "flying" his aircraft in the vicinity.

The precision with which intruder bearing angle information should be reported to the pilot to achieve optimal detection was also studied (Experiment 2). Detection reached a maximum level when the standard deviation of bearing angle information was reduced to 1.5 degrees. Greater precision did not improve detection performance while lower precision markedly impaired performance. This finding should be considered when establishing design specifications for PWI displays.

Earlier detection of an intruder increases both the range and the time available to the pilot for observing the intruder. The usefulness of the increased range and time was determined in terms of the pilot's ability to evaluate the threat of intruder aircraft (Experiment 4). With greater detection range and observation time, judgement of the intruder's course was generally more correct. Also, more time remained after the final decision of the existence of a collision threat when the time available for observation was greater. With an available observation time of 40 seconds there was about twice the amount of time remaining after final decision as with an available time of 20 seconds (see table 3-15). Thus, early information from PWI is beneficial in the evaluation of threat.

The effect of information from PWI on the pilot's maneuvering performance was also investigated (Experiment 5). The results show that when an intruder on a true collision course was detected, a maneuver resulted almost 100 percent of the time, regardless of the amount of observation time. With non-collision courses, earlier warnings resulted in a higher maneuver frequency and earlier maneuvers. The effectiveness of a maneuver depends upon such factors as closing rate and aircraft maneuvering capability. For closing rates up to 900 knots, evasive maneuvers reaching 3 g's were effective when observation time was at least 20 seconds. For a given closing rate, increasing detection time or range increased the separation resulting from the maneuver. In a few cases involving intruders not on collision courses, the unnecessary maneuvers might have initially placed the aircraft on a collision course. For the most part, however, unnecessary maneuvers were in the safe direction.

In developing a means for generalizing visual detection data from the simulator and laboratory to the real world, the relationship between intrinsic detection frequencies (i. e., those obtained with foveal fixation of target region) and search detection frequencies was investigated (Experiment 6). If, regardless of specific characteristics, targets which have equal intrinsic detection probabilities also have lower but identical search probabilities, then generalizations about search detection probabilities in the field can be made, with a reasonable amount of confidence, on the basis of intrinsic detection probabilities determined in the laboratory. The experiment indicated that targets differing only in size and brightness but equal with regard to intrinsic probability of detection also have the same search probability of detection if these targets subtend visual angles of 6 minutes of arc of less. For larger targets, the search probability of detection is higher than that predicted on the basis of the intrinsic probability of detection.

SECTION V

PWI RANGE REQUIREMENTS

A INTRODUCTION

Maneuvers which were executed in the simulator in Experiment 5, even those executed at short ranges, were generally effective in evading collision threats. However, these results apply only for an aircraft having a high acceleration capability, such as the F-100A which was simulated. Therefore, when more moderate maneuvers are employed the required detection range was estimated partially on experimental results and partially on data from other sources. These estimates were also based on the following assumptions:

- A head-on collision encounter exists between the protected aircraft and one of the higher speed aircraft likely to be encountered during flight
- Only the one aircraft maneuvers
- The maneuver consists of a constant rate horizontal turn (the time required to establish the turn rate is neglected)

B METHOD

Aircraft were subdivided into general performance categories. The path displacement which an evasive maneuver should produce was established at a level which would assure clearance even if the direction of the maneuver were such as to initially reduce the impending miss distance (as dictated by rules of the road, for instance). This level was determined by examining collision decision frequency as a function of initial miss vector from Experiment 4, to ascertain the miss vectors for which collision decision frequency dropped effectively to zero. The time required for the maneuver, for several different turn rates, was then computed. This time was converted to range-at-maneuver based on anticipated closing rates. Required detection range was then estimated by extrapolating the curves of mean range-at-maneuver as a function of detection range from Experiment 5.

C CALCULATIONS

The categories into which the aircraft were subdivided and their typical characteristics are shown in the headings of table 5-1. Maximum anticipated closing rates for each class were extracted from Appendix B of Reference 6 (see List of References). These rates were estimated from the maximum altitude of the aircraft in question and the expected performance characteristics of the population of aircraft at that altitude.

As noted previously, the displacement which should result from the maneuver was established as equal to the miss vector for which collision decision frequency dropped effectively to zero (figure 3-11 or 3-12). The 2000-foot value so obtained was factored proportional to wingspan to yield a 500-foot displacement for the 25-foot wingspan aircraft and a 2400-foot displacement for the 120-foot wingspan aircraft. The use of the maneuver frequency data from Experiment 5 for this purpose would have represented a more conservative approach, yielding required displacements of almost four times those employed here. This latter approach was felt to be too pessimistic, since the execution of a maneuver in Experiment 5 may have been only precautionary, and did not necessarily imply that the subject had decided that a collision was impending.

Maneuver times were calculated based on 30-degree and 45-degree bank angles, except that the 45-degree case was omitted for the lowest performance class as beyond its capability. The acceleration components in the horizontal plane for these two bank angles are 18.6 and 32.2 feet/second^2 respectively. Maneuver time was calculated from the approximate expression: $t = \sqrt{2s/a}$ where

t = time required for maneuver,

s = displacement which maneuver should produce

a = acceleration component in the horizontal plane.

The range at which the maneuver should be initiated was then determined using the previously discussed maximum anticipated closing rates. The resulting maneuver time and maneuver range values are both included in table 5-1.

Required detection range was estimated by extrapolation of the mean-range-at-maneuver data from Experiment 5. This extrapolation is a questionable procedure, but it is the only one available. It was accomplished by plotting the experimental results on log-log paper, scaled again for the wingspans of interest (figure 5-1). Only one curve is shown for each wing span since the experimental results are relatively independent of initial time. The only justification for using log-log paper is that the three experimental points lie on a relatively straight line for this coordinate system. Extrapolation was done graphically using the straight lines fitted through these points. These results are also included in table 5-1 under the listing: 50-Percent Success Detection Range.

D. DISCUSSION OF RESULTS

The previously mentioned listing was chosen advisedly. Because the extrapolation described was based on a mean range at maneuver, the detection ranges shown will result in the displacements established as desirable, as a result of the maneuvers employed, only 50 percent of the time. Unfortunately, the experimental data indicates that there is no detection range which will produce the desired separations with a probability approaching 100 percent. As the probability of success associated with the extrapolation curves is increased, the curves drop and approach horizontal lines. For instance, the corresponding curves for a

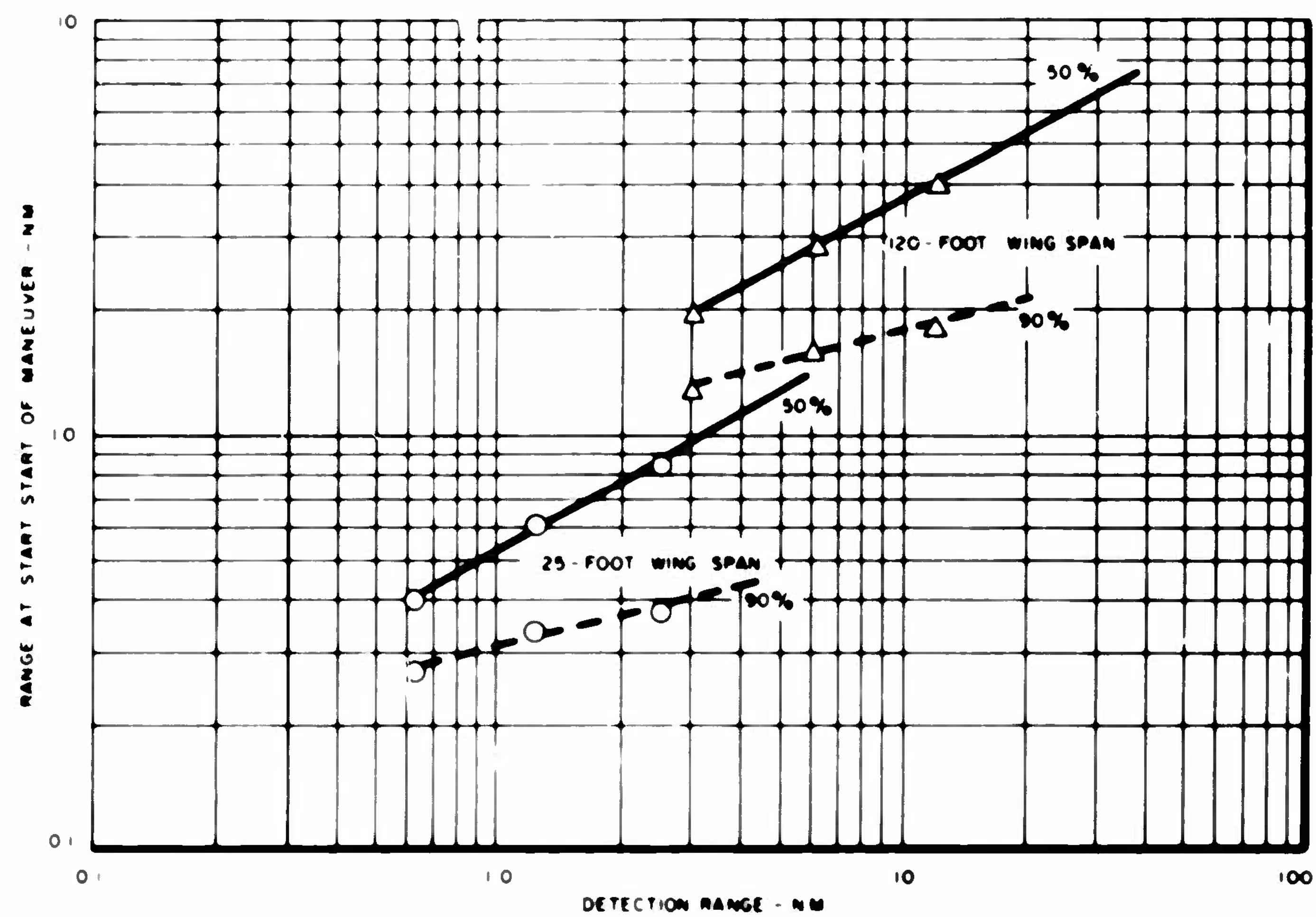


FIGURE 5-1 RANGE AT MANEUVER INITIATION AS A FUNCTION OF DETECTION RANGE

90-percent probability of success are approximated by the dotted lines in figure 5-1. These curves are based on the experimental data plotted in figure 5-2. The use of the dotted curves to estimate detection ranges may be meaningless for the following reasons:

- The required maneuver ranges are so far outside the span of the experimental data that the described extrapolation loses all credibility, and

- The required detection ranges which would result would certainly be beyond visual detection range, under any atmospheric conditions.

It should be noted that although a horizontal turn is always an effective maneuver for the head-on encounter employed herein, there are encounters for which a horizontal turn has little effect on miss distance except in the case of the lowest performance class, which are capable of very short turn radii. Thus, although closing rates are generally lower than in the head-on case, an encounter in which the paths cross at 90 degrees, for instance, generally is a worse case for achieving horizontal separation by employing a horizontal turn maneuver. A possible alternate maneuver in the latter case is to descend rather than turn. Such a maneuver will generally provide adequate vertical displacement (adequate is defined as 600 feet for the transport classes and 125 feet for the "business" class based on scaling the vertical miss distance corresponding to zero collision decision frequency from Experiment 4) with detection ranges of the same order as shown in table 5-1. The separations achievable with climbing maneuvers are generally less satisfactory and in many cases inadequate, depending on the aircraft's rate of climb capability at its operating altitude.

E. CONCLUSIONS

A PWI should have a range capability at least equal to the 50-percent success values shown in table 5-1. With this capability, it can be expected to reduce collision probability by about 50 percent which is not an impressive figure. Any increase in range capability will enhance the probability of success, provided the increased range is within visual detection range, but can never be expected to yield a probability of success approaching 100 percent.

These projections are based on the pilot's selection of the most appropriate evasive maneuver, on a decisive execution of the maneuver and on the absence of any conflicting maneuver by the other party to the encounter. The means for realizing these latter conditions are beyond the scope of this study.

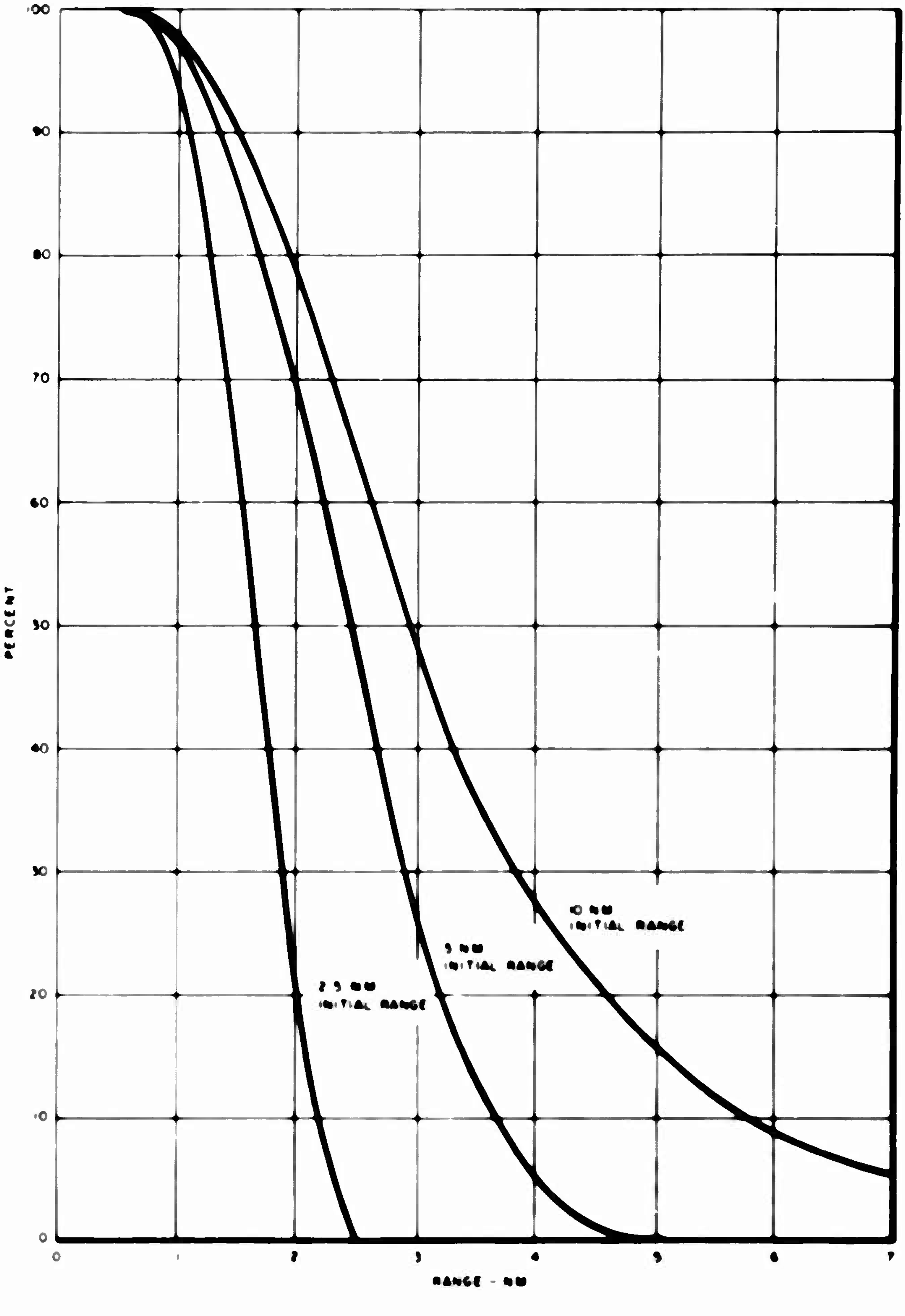


FIGURE 5-2 PERCENT OF OCCURRENCES OF RANGE-AT-MANEUVER GREATER THAN RANGE SHOWN

TABLE 5-1

NUMERICAL DATA

Aircraft Class	Personal	Business	Propellor-driven Transport	Transport
Typical Wingspan (feet)	25	25	120	120
Maximum TAS (knots)	100	240	330	410
Maximum Altitude (kilofeet)	10	20	30	40
Maximum Rate of Descent (feet per minute)	700	1800	3000	5000
Sea Level Rate of Climb (feet per minute)	400	900	2100	2800
Maximum Anticipated Closing Rate (knots)	300	660	740	820
Required Horizontal Displacement (feet)	500	500	2400	2400
Time Required for Maneuver (seconds)				
30° bank (1.16 G's)	7.35	7.35	16.0	16.0
45° bank (1.41 G's)	-	5.58	12.2	12.2
Range at Maneuver Initiation (nm)				
30° bank	0.613	1.35	3.29	3.64
45° bank	-	1.02	2.50	2.78
50-Percent Success Detection Range (nm)				
30° bank	1.3	5.5	8.0	9.2
45° bank	-	3.3	4.6	5.8

SECTION VI

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions summarize the empirical findings in the evaluation of PWI. These conclusions have been based on simulated flying situations in which the intruder's course was always unaccelerated. This fact was known by the subjects. All problems studied were restricted to two aircraft encounters.

1. PWI provides improvement in detection probability. The amount of improvement resulting from the use of a warning device is related to the amount of information which the device provides. The more information provided the greater the improvement in detection. (Experiment 3.)

2. Earlier detection results in both earlier evaluation of intruder threat and in earlier maneuvering, when necessary. (Experiment 4.)

3. If a collision situation exists, it is almost always correctly judged as such, if detected. (Experiment 4.)

4. Detection of a non-threatening intruder often results in an unnecessary maneuver. In general, the resulting maneuvers are in the safe direction; however, in some cases they may create a collision situation. (Experiment 5.)

5. This program was designed to provide a qualitative evaluation of PWI. Indiscriminate generalization of the quantitative data to real world situations would be premature and should be avoided at this time.

Recommendations

The findings of the present research program provide a means for planning how real-world research may be carried out most efficiently. A real-world program will serve to validate the simulator research as well as to further evaluate PWI. The following recommendations concerning future research are offered.

1. The determination of the effect of the various levels of PWI upon detection performance in the real world may be carried out with ground observers. Detection could be correlated with prevailing meteorological conditions, which may be categorized in any one of several possible ways and statistically controlled for in an ad hoc manner. This would circumvent the inability of the experimenters to independently control real-world visual conditions.

2. Although real-world testing of the effect of PWI upon threat evaluation and maneuvering is desirable, it is beyond the scope of the present program to specify how the difficulty of controlling variables in flight may be resolved. However, it is felt that some sort of operational testing should be undertaken.

APPENDIX A

SAMPLE FLIGHT PLAN

1. The Flight Plan given to the subject before take-off is as follows:

Route:

Islip (MacArthur Airport) direct to Riverhead (RVH) VOR direct to WilkesBarre (AVP) VOR airway 1504 to Milwaukee (MKE).

Altitude:

Climb to and maintain 20,000 ft.

Airspeed:

375 TAS, (Tentative)

Frequency:

MacArthur Ground Control 121.9

2. The following is a chronological list of the actions which will have to be taken by the air traffic controller and subject during the flight. It should be realized that action items of the subject are anticipated only.

Step	By	Action
1.	Subject	1st call to ground control Freq. 121.9, Jet 5634 IFR to MKE
2.	Ground Control G. C.)	Ans. (give route clearance) ATC clears Jet 5634 to Gen. Mitchel Apt. via RVH, AVP, climb to and maintain 20,000 ft.
3.	Subject	Jet 5634 - repeats clearance

Step	By	Action
4.	G. C.	Change to 119.3 for departure
5.	Subject	Changes to 119.3 and calls dep control
6.	Departure Control	Jet 5634 cleared for T. O. Runway 6 direct to RVH. Climb to 2000 ft. Contact NY Center on 124.3 immediately after T. O.
7.	Subject	Acknowledge step 6
8.	Subject	Take-off, climb to 2000 ft., proceed to RVH VOR on 117.2
9.	Subject	Change to 124.3 Calls N. Y. Center
10.	N. Y. Center	Roger, have you in radar contact. Cleared to 20,000 ft. Cleared to proceed on course from RVH. Rpt leaving 10,000 ft. and arriving 20,000 ft.
11.	Subject	Acknowledge Step 10
12.	Subject	Rpts. RVH. Changes AVP VOR, 117.8 on bearing 115° from AVP VOR
13.	Subject	Rpts. leaving 10,000 ft.
14.	Subject	Rpts. arriving 20,000 ft.
15.	N. Y. Center	Change to N. Y. Center freq. 120.2
16.	Subject	Acknowledge and changes to 120.2 Calls cntr on 120.2
17.	N. Y. Center	Roger, rpt. WilkesBarre
18.	Subject	Acknowledge step 17
19.	Subject	Rpts. over AVP. Changes heading to 289° from AVP/VOR Now on airway 1504

Step	By	Action
20.	N. Y. Center	Roger, Jet 5634 climb to and maintain 22,000 ft. Cleveland center unable to approve 20,000 ft. Contact Cleveland Center 128.3 at Stonyfork. Rpt leaving 20,000 ft. and arriving 22,000 ft. the freq.
21.	Subject	Acknowledges Step 20
22.	Subject	Begins climb. Rpts. leaving 20,000 ft. to N. Y. Center
23.	Subject	Finishes climb. Rpts. arriving 22,000 ft. to N. Y. Center
24.	Subject	Changes to BFD VOR 116.6 Proceeds on airway 1504.
25.	Subject	Triangulates on ELZ VOR to find Stonyfork Arrives Stonyfork. Changes to 128.3 Rpts. Clevelend Center
26.	Cl. Center	Roger, Jet 5634, Rpt. ERI
27.	Subject	Acknowledge Step 26
28.	Subject	Arrive BFD VOR. Proceeds on airway 1504. Heading change
29.	Subject	Changes to ERI VOR, 115.7
30.	Subject	Arrives ERI. Proceeds on airway 1504. Heading change. Rpts. Cleveland Center
31.	Cl. Center	Roger, Jet 5634, Rpt Detroit Center, 127.5
32.	Subject	Acknowledges Step 31, Changes to 127.5. Calls Detroit Center
33.	Detroit Center	Roger, Jet. 5634, Rpt. QG
34.	Subject	Changes to QG VOR, 114.3, No heading change.

Step	By	Action
35.	Subject	Arrives QG. Reports to DET Center. Proceeds on airway 1504. Heading change. Changes to SYM VOR, 117.8.
36.	Detroit Center	Roger, Jet. 5634, Rpt. MKG
37.	Subject	Acknowledge Step 36 Arrives SYM VOR. Proceeds airway 1504. Heading change
38.	Subject	Changes to MKG VOR, 115.6 Heading Change
39.	Subject	Arrives MKG. Proceeds on Airway 1504 Heading change. Call Detroit Center
40.	Detroit Center	Roger, Jet. 5634, Call Chicago Center, 131.2
41.	Subject	Acknowledges step 40 Changes to 131.2 Calls Chicago Center
42.	Chicago Center	Roger, Jet 5634. Cleared to MKE VOR. Descend 22,000 and reaching Minnow
43.	Subject	Acknowledges Step 42 Begins descent. Call Chicago Center. Changes maps
44.	Subject	Arrives 5000 ft.
45.	Subject	Triangulates on PMM VOR, 112.1 and MKG VOR to find Minnow
46.	Subject	Arrives Minnow. Calls Chicago Center
47.	Chicago Center	Roger Jet 5634, Contact Milwaukee Approach Control, 126.2
48.	Subject	Acknowledges Step 47, Changes to 126.2 Call MKE App. Cont.

Step	By	Action
49.	MKE App. Cont.	Roger Jet 5634. Rpt Seaweed for positive Radar contact.
50.	Subject	Changes to MKE VOR 116.4. No head changes
51.	Subject	Triangulates on OBK VOR, 113.0 and M' E VOR to find Seaweed
52.	Subject	Arrives Seaweed. Calls MKE app. cont.
53.	MKE App. Cont.	Roger, Jet 5634, have you in pos. radar contact. Turn left to 230° heading
54.	Subject	Acknowledges Step 54. Turns left to 230°
55.	MKE App. Cont.	Jet 5634, cleared for an ILS approach via radar vector to the MKE LOM. Descend to 2000 ft.
56.	Subject	Acknowledges Step 55. Begins descent
57.	Subject	Arrives 2000 ft.
58.	MKE App. Cont.	Jet 5634, turn right to 305° heading. Intercept ILS course. Complete approach.
59.	Subject	Acknowledges step 58, turns right to 305° head. Lands.

APPENDIX B

INSTRUCTIONS READ TO SUBJECT - EXPERIMENT 4

"This experiment in which you are going to participate is one of several designed to evaluate the effectiveness of PWI systems. Although no such system is going to be employed here, the purpose of this experiment is to determine how well pilots can judge whether or not a plane is going to collide with their own plane. Collisions and near misses are going to be simulated and you are to decide on the course of an intruder plane as you would if you were actually flying. You are going to be seated in the simulator cockpit but will not fly the plane. The flight of the simulator will be set on a straight and level course. Your task will be to look where told and to follow the course of a model plane representing an intruder which will be projected on the dome surrounding the simulator. You are to judge the course of the intruder in terms of whether or not it will collide with your plane. You are to report your judgment from the time the target appears until it disappears from view. You will give your reports by continuously pressing one of these three buttons as you see the buttons are marked "COLLISION", "MISS", and "UNDECIDED". Only one button may be pressed at a time. You will be told the exact location of the target. You are to press the undecided button as soon as you see the target - it will not be moving at this time. Your pressing the button will serve as a signal that you are ready for the next trial. The target will then start moving along a course and you are to press the button indicating your judgment of whether it is on a collision course or not. You may change your decision as frequently as necessary.

"The important points to remember are

1. React in as realistic a way as possible, i.e., try to make your decisions as if this were a real flying situation.

2. Press the appropriate button as soon as you make a decision.

3. Change your respo se whenever your decision changes. If not sure, press the "UNDECIDED" button.

4. You will consider the intruder to be on a collision if in the real situation you would eventually maneuver to avoid it."

APPENDIX C

INSTRUCTIONS READ TO SUBJECTS - EXPERIMENT 5

"This experiment is one of several designed to evaluate the effectiveness of PWI systems. Although no such system is going to be used here, the purpose of this experiment is to study the maneuvering of pilots who are confronted with a plane which may collide with them.

"You are going to be seated in the simulator cockpit. After you are settled take up a course of 0° heading at an altitude of 10,000 feet and an air speed of 350 knots. You should try to maintain this course as closely as possible throughout the session. Try to do this without spending all of your time looking at the instrument panel.

"Your task will be to look where told at an image representing an intruder and to follow the course of the intruder as it approaches you. If you think that it is necessary to execute an avoidance maneuver you may do anything you feel is necessary. As you do this press the maneuver button on the stick. This will indicate to us that a maneuver is intended. If you do not think that an avoidance maneuver is necessary do not change your course. The intruder will continue along it course until the run is completed.

"You may execute a maneuver at any time during a run. Do not make the maneuver any more violently than you have to. The courses you will be shown will include misses, near misses, and collision. You should try to act as much as possible as if this were a real flying situation. Your maneuver should be as realistic as possible.

"If there are any questions you may ask them at anytime. If anything appears out of the ordinary during the experimental session please notify the simulator operator over your microphone."

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TABLES

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Systems Research and Development Service, Federal Aviation Agency, Atlantic City, New Jersey. A STUDY OF REQUIREMENTS FOR A PILOT WARNING INSTRUMENT FOR VISUAL AIRBORNE COLLISION AVOIDANCE by J. Catalano and C. McKown, Final Report, Dec. 1963. 108 pp. incl. illus., (Contract No. FAA/BRD-322, Project No. 110-504, Report No. RD-64-88).

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